ELECTRIC TRACTION

A. H. ARMSTRONG

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ELECTRIC TRACTION

Section 13 from the

STANDARD HANDBOOK

FOR

ELECTRICAL ENGINEERS

BY

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Transport.

FOREWORD.

This book comprises Section 13 of the Standard Handbook for Electrical Engineers and is reprinted in this form especially for the Circulation Department of the Electric Railway Journal. This section is intended to cover the electrical engineering of electric railroading. No attempt is made to treat road location, track building, etc., which are purely civil engineering problems.

Other phases of electrical engineering of a general character are, of course, treated in other sections of the Standard Handbook, but the material herein will, it is hoped, be found of practical value to railroad men.

Transport

SECTION 13

ELECTRIC TRACTION

Covering the Selection, Calculation and Design of the Complete Equipment for any given Schedule and Track; and the Design, Construction and Cost of Distribution Systems, for Trolley Voltages Ranging from 600 volts d.c. to 11000 volts a.c.

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SECTION 13.

ELECTRIC TRACTION.

INTRODUCTION.

(Cross references refer to paragraph numbers in the section where the reference appears.)

1. The electric motor has become recognized as the **type of motive power** par excellence for all city railways, whether overhead, on the surface, or underground, and has increased in capacity from the original 7-hp. motors with double gearing to the 550-hp. gearless motors, used on the New York Central 100-ton locomotives. **The work which the electric railway motor is called upon to perform** is vastly varied in character and scope, ranging from the operation of small single truck cars at a maximum speed of 15 miles per hour to the propulsion of a 1000-ton passenger train at 60 miles or more per hour. City railway systems have adopted electric motors in place of the horse, cable and steam locomotive, and the suburban railway field is also largely electrified, while electric lines parallel and successfully compete with steam lines operating between all principal cities in the more populous districts. Furthermore, the success attending electric motor operation has led to several installations involving the use of heavy electric locomotives which will replace steam locomotives on certain sections of trunk lines.

2. To meet such widely different operating conditions it has been necessary to adopt a **type of electric motor** permitting great flexibility in design and capable of extreme development, and the almost universal use of the series-wound d.c. motor operating at 500 to 600 volts has demonstrated the fitness of this type of motor for all around conditions. During all the succeeding years of development, no type of motive power has been perfected equaling in efficiency and general adaptability, the d.c. series motor, and so far as the car equipment is concerned, there is no reason to contemplate a change in type of motive power. Unfortunately, the car equipment constitutes but a single link in the railway distribution system, and the series-wound d.c. motor, limited to a potential of 600 to 1200 volts, entails expenditures in the first cost and cost of operating the distributing system, which has given rise to the adoption of other types of motive power for certain classes of service.

3. The underrunning overhead trolley suspended over the car between the rails is still an excellent **method of secondary distribution** for the smaller city service lines and interurban roads, but the demand for a greater power than can be collected from a suspended copper conductor has led to the introduction of the third rail, of both the unprotected and protected types. Thus, while the trolley furnishes a conducting medium for the 200 or 300 hp. demanded by a high-speed car, the third rail can supply the 4000 hp. required for the operation of electrically hauled trains at the New York Central terminal.

4. The early **d.c.-series motor** was designed with **double gearing** This was soon superseded by the **single gearing** which is common practice to-day. With the application, however, of the electric motor to high-speed locomotive service, the way was opened for the next step in advance, the **gearless motor,** and the New York Central electric locomotives attest the success of the latest development in d.c. series motor design.

5. There was but one step left in the development of the d.c. series motor, and this consisted in making use of the years of experience in the design of 600-volt railway motors, and increasing the voltage which can be successfully commutated, and there are in construction in the United States four interurban electric railways upon which it is proposed to use **1200-volt d.c.-series motors** of the geared type. The high-potential d.c. motor offers no special features in design, being rather the embodiment of hard bought experience in the development of the 600-volt motors. The

adoption of the 1200-volt motor carries with it certain economies in the first cost of installing electric railway systems which justify the complete re-design of control, rotary converter and switchboard apparatus, a matter of applied present knowledge rather than of untried experiment.

6. During the past four years an entirely **new type of motive power** has been developed which can be operated directly from the a.c. generating and distributing systems without the necessity of having any intermediate rotary converter. The **a.c. railway motor** was foreshadowed in the early experiments of Thomson and others, but it required the experience gained in d.c. motor design and the introduction of low-frequency supply before the early experiments could be carried to fruition. A frequency of 25 cycles or lower is required for the successful operation of the a.c. railway motor, and while a lower frequency offers material advantages in motor design, the gain however, is hardly sufficient to offset the commercial advantage of adopting 25 cycles in order to utilize the enormous generating capacity now in commercial operation.

7. The **a.c. single-phase railway** motor can be operated with a **trolley potential** of several thousand volts, far beyond the present possibilities of d.c. motor design, and with the advantage of lower first cost of secondary distribution and elimination of the converter sub-station, the a.c. railway motor system offers a material reduction over the d.c. rotary converter system in the first cost and cost of operating extended railway systems. Owing to these material reductions in first cost, many railroad problems can be considered from an electrical standpoint, which were hitherto closed on account of the excessive first cost of electrifying with the rotary converter system. Thus, while the high potential trolley is not a factor in the operation of city or suburban roads, running through densely populated districts, it does offer new possibilities in districts requiring an infrequent service. Furthermore, it opens the door for the electrification of certain sections of main trunk line roads now operated by steam, as it materially reduces the high fixed charges incident to electrification with d.c. motors, and thus helps to bring the balance in operating expenses in favor of electrification.

8. Although not in general use, the **three-phase induction motor** has been installed and operated as a railway motor with considerable success. Owing to the American prejudice to the complication of the double trolley and the semi-synchronous character of this type of motive power, only one induction railway motor installation has been made in America, but there are certain classes of work for which the three-phase induction motor is well adapted, and its qualifications and limitations should be understood when considering problems of heavy electric traction. The successful development of the single-phase a.c. motor has undoubtedly curtailed the field of application of the three-phase induction motor for railway purposes, but for certain classes of work the three-phase induction motor possesses qualities not shared by any other type of motor, and the installation of induction railway motors will be made where the conditions are favorable.

9. There are three **types of motors available for railway** service, giving rise to three systems of distribution.

(1) The d.c. series motor of 600 to 1200 volts, fed from rotary converter or motor generator sub-station, tied into a high potential three-phase alternating-current transmission system.

(2) The a.c. series motor fed directly from an a.c. high-potential transmission system through intermediary step down transformers.

(3) The a.c. three-phase induction motor fed directly from an a.c three-phase transmission system through step-down transformers.

All three systems enjoy the advantage of a.c. generation and transmission of power at high potential, the d.c. and induction motor system demanding multiphase generation, while single-phase generation and distribution best serves the needs of the single-phase a.c. motor system.

10. All **railway estimates** are based upon the performance of the rollin stock, as tnis determines the type of equipment to be used, its capacit the possibilities of schedule speed, the power input to the train, both ma imum and average, this in turn determining the characteristics of the lc *potential distribution system,* whether trolley or third rail, its capacit

etc., thus leading up to the determination of sub-station capacity, and finally the capacity and cost of the generating station. It is important therefore, that the characteristics of the different types of motive power be thoroughly understood, as a false assumption or error in the preliminary calculation of motive power capacity and train energy consumption may lead to very serious errors in laying out the entire generating and distributing systems.

11. The various **steps to be followed in the determination of the proper relation of motive power equipment, distribution and generating systems,** are as follows:

(1) A knowledge of train-resistance values.

(2) Calculation of possible schedule with the frequency of stops, train weight and other fixed factors entering into the problem.

(3) Determination of train input as obtained from train resistance and energy consumption values.

(4) Determination of motor capacity.

(5) Calculations of train diagrams.

(6) Determination of capacity of low potential distribution system and sub-stations.

(7) Determination of generating station capacity.

(8) Estimate of cost of the various parts of the electric railway system as determined by the capacity found above.

(9) Approximate cost of operation.

(10) Approximate gross income as determined by comparative statistics.

(11) Dividend earning power of road.

TRAIN RESISTANCE.

12. Careful **experimental tests** carried out during the past few years with electric locomotives and motor-cars have thrown new light on the much discussed question of train resistance at the higher speeds. Without, in any way, disparaging the care taken in tests made with steam locomotives, it was not until electrical methods of measuring power introduced greater accuracy than obtainable by the steam indicator, that consistent results became obtainable with light trains operating at very high speeds.

13. The electric motor was the means of introducing the **single-car train** operating at speeds up to 70 miles per hr., concerning the operation of which no data were extant. It was soon found that such a car operating alone required an input out of all proportion to the power required to propel a train composed of several such cars operating at the same speed, and new adjustments had to be made in train resistance formulas then existing.

14. During the spring of 1900 a series of tests were made by Mr. W. J. Davis, Jr., on the Buffalo & Lockport Railway, which consisted in running a **40-ton electric locomotive alone and with trailers** at speeds approaching 60 miles per hr., as a maximum, and these tests probably constitute the first consistent attempt to utilize the benefits of greater accuracy which electrical methods of recording afford. Since then other tests taken under better conditions and with different classes of equipment, afford data from which it is possible to predict, with a considerable degree of accuracy, the total resistance, wind, bearing and rolling, opposing the movement of cars or light trains up to speeds of 100 miles per hour.

15. Train resistance may be **expressed in pounds tractive effort** at the rim of the driving wheels of the prime mover of a train. It thus includes all losses in bearings, looses due to rolling friction, bending rails, flange friction, etc., and finally the wind resistance loss which is itself made up of head-on resistance, skin or side resistance and eddy currents caused by the suction at the rear of the car or train. All these variables depend upon the condition of bearings, design of trucks, condition of the road-bed, shape and cross section of cars, direction of wind, etc., so that any tests, to furnish authorative data, must be sufficiently comprehensive to eliminate the errors of purely local conditions. As no such elaborate series of tests have yet been made, any formula predicated on the data available, must at best be approximate.

16. Data are available on locomotives and cars of modern **construction** as follows:—

Buffalo and Lockport experiment in 1900.

Zossen High Speed Tests in 1902-3.

Tests on New York Central Type Locomotive at Schenectady, 1905-6.

Tests on Car No. 5 at Schenectady, 1906.

Tests made by the Electric Railway Test Commission, on the test car "Louisiana," 1904-5.

New York Subway Tests, 1905.

Many isolated tests have been made from time to time other than those mentioned above, but either the data were not sufficiently complete or the conditions were too unfavorable to justify using the results obtained as applying to other than local conditions. The data comprised in the tests given above are sufficiently general, as they include the operation of trains varying from a single 35 ton car to a train of 532 tons, and speeds up to 130 miles per hr. in the Zossen Tests.

17. The **laws governing the friction of journal bearings** are fairly well understood and the fact that such bearing friction constitutes part of the resistance opposing the motion of a train, need introduce no undetermined factors. Such friction losses decrease with the pressure on the bearings and are a function of the speed. Hence, the expression, $f = A + B S'$.

Where "f" is bearing friction expressed as pounds per ton, A and B are constants determined by experiment and S is the speed expressed conveniently in miles per hour.

18. Rolling friction is due to the friction of metal rolling on metal where the surfaces are not perfect, the bending of rails due to insufficient upport, such as ties or ballast, or too light rail for the weight carried, flange friction between rail and wheel flange; all these factors being proportional to speed and hence represented by a straight line function. As bearing and rolling friction are both approximately proportional to the speed they may constitute the first two terms of a train resistance formula,

$$f = A + B S.$$

19. The **constant**, A, has been **determined by experiment** to vary from 3.5 to as high as 12 pounds per ton, depending upon the weight concentrated on the journal bearings. Both the Zossen cars and the New York Central locomotive have indicated in test a value of A = 3.5 to 5, both the cars and locomotive having a weight of approximately 200,000 pounds concentrated on twelve journal bearings. Tests on Car No. 5 at Schenectady on the other hand, gave a value of approximately 8.5 for A, this car having 68,800 pounds on eight bearings. Hence, the impossibility of giving a single value to A that will obtain over wide variation in type of equipment.

20. The **factor**, **A**, can be **expressed in terms of the train weight** and the following purely empirical term is suggested as agreeing remarkably close with experimental results.

$$A = \frac{50}{\sqrt{W}}, \text{ where } w = \text{tons weight of train.}$$

In using such a term it is necessary to limit A to a minimum value of 3.5.

21. Values of A.

20-ton car		11.2
30 "	"	9.12
40 "	"	7.9
50 "	"	7.07
60 "	"	6.45
80 "	"	5.58
100 "	"	5.00
200 "	"	3.54

22. Rolling friction and bearing friction, increasing with the speed and giving rise to the **coefficient** of S **in the second term** of a train resistance formula, can be **determined experimentally** by operating a train with and against a wind of known velocity. Thus, given a wind of say 10 miles per hr. in the direction of the test track, a series of runs made at 40 miles per hr. against and 60 miles per hr. with the wind would give the same condition as regards wind resistance, that is, 50 miles per hr.; while any difference in the total train resistance found should be caused by the difference in rolling and bearing friction obtaining at 20 miles per hr., the difference in relative speeds of the train. Unfortunately the published data of the Zossen Test are incomplete in this respect, and offer no material upon which to place a value for the second term coefficient. Other tests taken for the purpose give values of B for speeds up to 80 miles per hr. with trains of any composition, and as the effect of B is small with heavy trains and almost negligible with single cars operated at high speed, any errors introduced by reason of insufficient data, do not seriously affect the accuracy of a train resistance formula as applied to the classes of equipment commonly met.

23. Values of B obtained experimentally vary from .03 to .07, depending upon the type of equipment and condition of track. For practically all operating conditions a value of B = .03 will give sufficiently accurate results, using higher values of B for very light equipments (under 30-ton cars) and poor track conditions, such as too light rail, accumulations on rail, etc.

24. By far the most important term of a train resistance formula for light trains is the term expressing the relation between **effect of wind** and speed of train. It is in this term that the many elaborate tests taken with steam locomotives have failed in affording accurate data, especially for very light trains operating at high speeds. Such tests have usually been made with either steam indicator or with dynamometer car as the means of determining the effect of wind pressure. The indicator card included in its readings all the intermediate internal friction losses of the locomotives, thus making results obtained by its use of small value when applied to other types of motive power having much smaller internal losses. The dynamometer car, while giving accurate readings of the draw-bar pull required to haul the succeeding trailers, failed to indicate the amount of head-on wind pressure, by far the larger proportion of the total resistance opposing the progress of a light train at high speed. Hence, the tendency to discard in a large part, the experimental data obtained from steam locomotive tests and place reliance upon the data obtained from such tests as the series listed (see **16**).

25. Tests made upon small models (Goss in 1897) and by means of whirling surfaces, seem to indicate that wind pressure increases as the square of velocity. In 1894, Kernot published the results of tests showing values of C as in **26**:—

26. **Values of C.**

C = .004 for flat surfaces,
C = .0024 for octagonal prism,
C = .0020 for cylinder,
C = .0014 for sphere.

Where C = pounds per square foot; hence giving rise to the form, $f = C\,a\,S^2$, for the third term of a train resistance formula.

27. The **Zossen experiments** also indicated that the wind effect upon the car increased as the square of the speed, thus following along the line of laboratory experiment and previous experimental train tests by Davis in 1900.

28. The simplest and most accurate **method of making wind resistance experiments** consists in the coasting method, where train is allowed to drift until it reaches standstill, the rate of speed decrease and elapsed time being accurately noted. The efforts of most experimenters have been directed toward securing such data during periods of no wind in order to eliminate this troublesome feature, but a series of runs taken with and against a wind of known velocity offers much data not otherwise

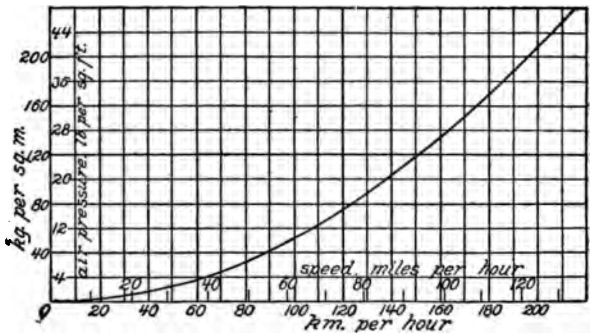
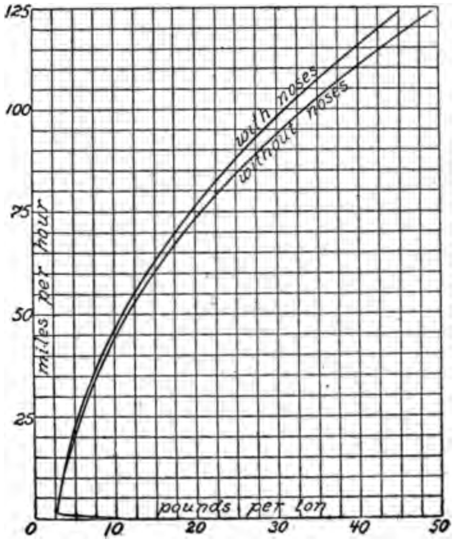


FIG. 1.—Wind-resistance tests (Berlin-Zossen).



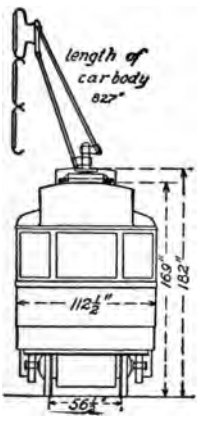


FIG. 2.   FIG. 3.

FIG. 2.—Train resistance (Berlin-Zossen tests 1903; Allgemeine car weight 206400 lb.; area 130 sq. ft.).

FIG. 3.—End elevation Allgemeine car (Berlin-Zossen tests).

available, and affords a ready means of solving directly for the coefficient of the second and third term of our train resistance formula.

29. For example, given a wind of 20 miles per hr. velocity, a series of **runs made with and against** such a **wind** will, at say 50 miles per hr. train speed, correspond to a wind pressure at 30 miles per hr. with the wind and 70 miles per hr. against the wind, the rolling friction being constant at the value obtaining at the train speed of 50 miles per hr. As the wind pressure varies as the square of the speed, such a series of tests affords a means of determining the coefficient of S^2 for the particular type of equipment used.

30. It has been found that the **shape of the car** end has a large **influence upon the coefficient** of S^2, such a result being reasonably expected from the results of experiments by Goss, Kernot and others: in fact, Davis checked up the values of .004 found by Kernot for flat surfaces. As a matter of fact, no cars or locomotives used for high speed service have perfectly flat ends, and hence, all experimental values of C have been found to be less than .004.

31. Little attempt has been made to construct **cars for least wind effect,** owing largely to a lack of full understanding of the benefits to be secured thereby. The cars used for high speed suburban service and all electric locomotives, with the single exception of the New York, New Haven and Hartford a.c. locomotive, are provided with partially rounded ends, with the result that the effective wind pressure is considerably reduced. A notable example of the extreme type of pointed nose design is the steel gasolene motor-car No. 7, of the Union Pacific Company, and such construction is a step in the right direction.

32. Values of C vary from .004 with perfectly flat ends to .0015 with noses of the extreme type, while the average rounded end suburban car and electric locomotive with sloping front give rise to values of C from .002 to .0025. Hence, the complete **train-resistance formula for single car operation** becomes,

$$F = A + B\,S + \frac{C a\, S^2}{W}$$

$$= \frac{50}{\sqrt{W}} + .03\,S + \frac{.002\, a\, S^2}{W}.$$

wherein, S is the speed in miles per hour; *a* the cross section in square feet, and W the car weight in tons.

33. It was found by Davis that somewhat larger coefficients for B and C obtained from the limited data of the Buffalo and Lockport tests, but much subsequent data seem to indicate values of B = .03 and C = .002 for cars weighing not less than 40 tons and having partially rounded ends.

34. Comparison of **calculated car-resistance** with the **actual test values** obtained from the Zossen experiments.*

	Speed of Car in Miles per Hour						
	10	20	40	60	80	100	120
A = 4.92.............	4.92	4.92	4.92	4.92	4.92	4.92	4.92
B S = .03 V..........	.30	.60	1.20	1.80	2.40	3.00	3.60
$\frac{C a\, S^2}{W} = \frac{.002\, S^2 \times 128}{103.2}$.	.25	1.00	3.96	8.93	15.90	24.80	35.70
F (calculated) =......	5.47	6.52	10.08	15.65	23.22	32.72	44.22
F (observed) =.......	3.5	5.5	9.10	14.9	22.8	33.3	46.00

* Here area = 128 square feet and weight = 103.2 tons (2000 lb.).

35. It is very possible that the higher values from test (Table **34**) obtained at the maximum speeds were influenced by reason of the track being not rigid enough for speeds of 120 miles per hour and hence increasing the value of B.

36. A consideration of **trains of several cars** makes it necessary to introduce an **additional factor** in the third term of the proposed train-resistance formula that shall express the effect of the wind resistance upon the sides of the succeeding cars. The head-on wind resistance is borne by the leading car and hence additional cars only

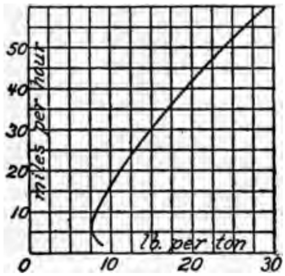


FIG. 4.—Train resistance (General Electric tests); weight 68,800 lb.

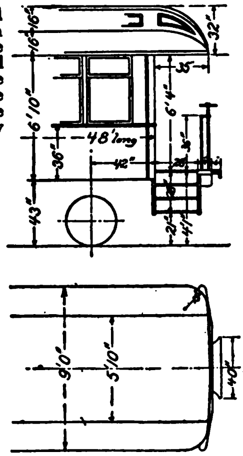


FIG. 5.—Elevation and plan, car No. 5 (General Electric tests).

introduce the additional skin friction offered by a train of greater length. The most reliable and exhaustive series of tests made with trains composed of a different number of cars is offered in the experimental runs of the New York Central locomotive No. 6000, during its 50,000 mile endurance run, hauling trailers up to a nine-car train.

37. Over 140 runs under different climatic conditions are condensed in the series of curves shown in Fig. 6, where the **train resistance** is expressed **in pounds per ton** weight of total train including locomotive. This set of curves indicates very plainly the reduction in train resistance per ton of train with the increase of train weight, such a reduction being largely due to the fact that the head-on wind resistance remains constant for any composition of train, being influenced only by the shape and cross section of the locomotive.

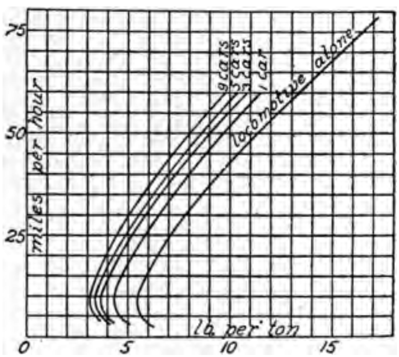


FIG. 6.—Train resistance runs (N. Y. C. locomotive and train).

38. The increase in skin friction along the surface of succeeding cars

corresponds closely to ten per cent. of the value of wind resistance as expressed by

$$f = \frac{C S^2 a}{W},$$

and for a **train of several cars** the third term becomes,

$$f = \frac{C S^2 a}{W}\left(1+\frac{n-1}{10}\right),$$

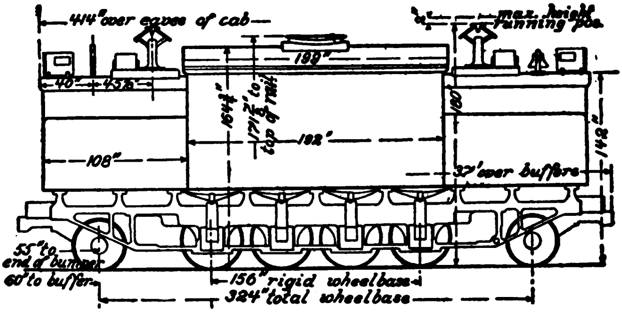


FIG 7.—N. Y. C. locomotive, side elevation.

where n = number of cars in the train. And the complete **formula for** any weight and composition of train becomes,

$$F = \frac{50}{\sqrt{W}} + .03\,S + \frac{.002\,a\,S^2}{W}\left(1+\frac{n-1}{10}\right).$$

The above formula is presented as being an expression of the knowledge of train resistance with the data extant, but any such formula is largely empirical, and is subject to change from time to time as the results of additional tests become available.

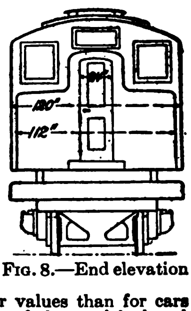


FIG. 8.—End elevation

39. Figs. 9 to 13 show **curves** based upon this **train resistance** formula, and express the resistance encountered with cars of from 20 to 60 tons weight operating singly and in trains. Also, for high-speed locomotive service, a series of curves is plotted for values up to nine-car train operation. All these results assume a perfectly level tangent track free from any foreign matter, such as street accumulations, sand, snow, etc. The effect of such matter is to seriously increase the value of B, hence the curve values should be increased if conditions are unfavorable.

40. Automobile train resistance runs to higher values than for cars operating upon steel rails, due to the character both of the road bed and tires. The irregularities of a highway or even a macadamized road make rubber tires a requisite for easy riding. A pneumatic tire will compress sufficiently so that the vehicle will not be compelled to ride over small surface obstructions, but the energy so saved is partly lost in compressing

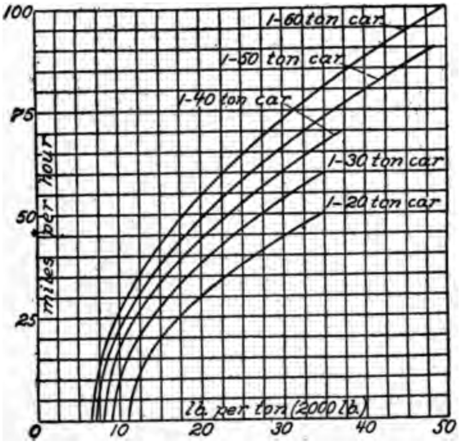


Fig. 9.—Train resistance, single-car train.

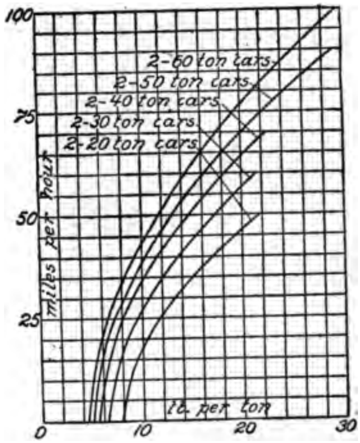


Fig. 10.—Train resistance, two-car train.

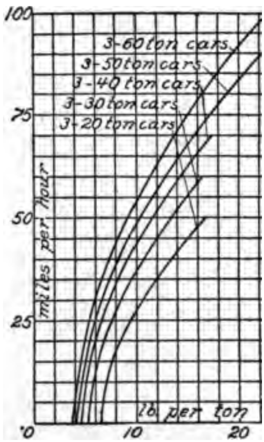


Fig. 11.—Train resistan three-car train.

and heating the rubber tires. Hence, the **tractive effort** required to haul a ton by means of rubber tires over asphalt paving can at best only approach the low train resistance values reached in railroad work with its superior rolling surface. In Fig. 14, is given the result of tests by Churchward on solid and pneumatic rubber tires on asphalt, the solid tires calling for less tractive effort owing to the superior character of the pavement. On country roads the solid tire will demand the greater tractive effort, owing to the ability of the pneumatic tire to better adapt itself to surface irregularities.

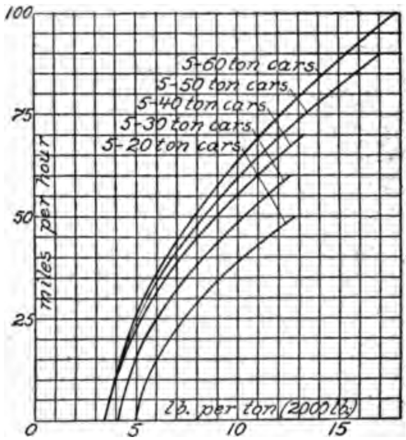


FIG. 12.—Train resistance, 5-car train.

41. It has also been demonstrated by experiment that the **tractive effort required to move a pneumatic tired vehicle** will depend upon the amount of fabric used to strengthen the rubber tire, the less fabric the more resilient the tire, and hence, the less tractive effort required to move the car. As the road beds over which motor cars operate vary over such a wide range, it is possible only to express some general values of train resistance over road beds of known character such as asphalt.

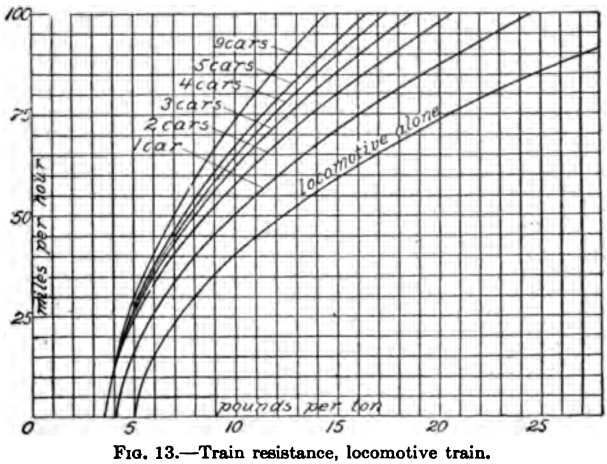


FIG. 13.—Train resistance, locomotive train.

42. Curves are usually expressed in degrees; a one-degree curve is taken arbitrarily as one in which a one hundred foot chord will subtend an

arc of one degree, or which is the same thing, will subtend a one-degree angle at the center. Hence the radius of a one-degree curve is approximately $\frac{100 \times 360}{2\pi} = 5730$ feet. Similarly the radius of any curve in feet is approximately $\frac{5730}{\text{No. of degrees}}$.

43. This custom of **rating curves by degrees** instead of by radius has undoubtedly arisen from the facility offered for laying out a curve in the field with a transit. For instance, a transit is set up at the point of curve, P C, and several angles, E A B, B A C, etc., each equal to one-half the degree of the curve are laid off. In the first of these directions one hundred feet is measured off and a stake driven. From this stake another hundred feet is measured off and lined in by the transit in its second position. One hundred foot chords are thus laid off until point of tangent P T is reached. As indicated in Fig. 15, this point is seldom at an even station, but is always indicated by a stake marked as shown, P. T. Sta. 102+80. Likewise with the point of curve, P C. In case the P C is not at an even station, the first stake of the curve is driven at an even station so that the remaining stakes of the curve will come at even stations. When the curve is sharp intermediate stakes are necessary and are driven at fractional distances.

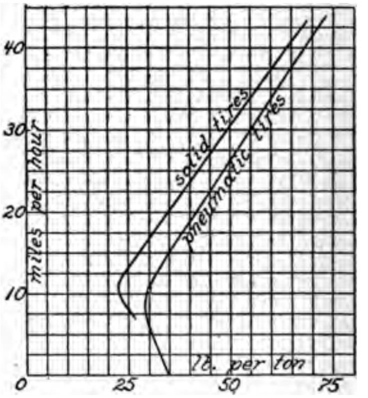


Fig. 14.—Train resistance, automobiles (asphalt roads).

44. It is evident that as the degree of curvature increases, this method of laying out a curve becomes less accurate and not particularly expeditious, therefore, the **sharp curves** met in city streets are generally rated as special work and are laid out and assembled in the works of the switch manufacturers before they are shipped, in which case the curves are generally rated by radius.

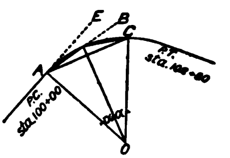


Fig. 15.

45. In **rounding a curve,** the **rolling friction** of a car is increased due to the increased flange friction, this increase being approximately at the rate of .5 lb. per ton for each one degree of curvature. As curves are of necessity of limited length they do not become a serious factor in train resistance calculations except in the calculation of locomotive constants where these are assigned to mountain grade service where both sharp curves and heavy grades occur.

46. Grades are expressed in percentage, being the ratio of distance train is raised to distance travelled, in other words, the ratio of the ordinate to the hypothenuse. A grade of plus one per cent means that the train is raised vertically one foot for each one hundred travelled, a minus one per cent grade is one where the train falls one foot for every hundred feet of distance travelled. It follows that a plus one per cent grade calls for a tractive effort of 20 lb. per ton, while a minus one per cent grade is equivalent to delivering a tractive effort of 20 lb. per ton to the train.

47. Where **gradients** are **small** it is not necessary to consider the *reduction in train* weight due to the angle of direction of travel to the true

horizontal, but for the **excessive grades** it is necessary to correct for effective trainweight.

Grades are divided in railway parlance into virtual grades and ruling grades.

48. Virtual grades are of limited length and are so called as they express the equivalent grade, a value always something less than the true grade. A train running at constant speed can surmount a certain grade as determined by the maximum tractive effort available. The moving train however may be compared to a revolving flywheel and has stored up in the moving mass a large amount of energy that is usually expended in heating the brake shoes during the period of stopping. This stored energy may be used to furnish the extra tractive effort required to ascend a heavier grade than the available locomotive tractive effort alone would permit, but in such a case the grade must be of short length. Hence, the actual grade may be considerably in excess of the virtual grade, provided it is so short that the inertia of the moving train can supply the additional energy required to ascend it.

49. The ruling grade means the maximum grade encountered on a given section of track and may be the actual grade, where such is of long extent, or the virtual grade, where the inertia of the train may be used to advantage in overcoming a heavier short grade. The **ruling grade of freight hauling roads** should be limited to two per cent or less when the topography of the country will permit, in fact, on a modern freight road any grade exceeding one per cent maximum would be considered excessive and demand the use of helper locomotives. While low grades are not so important on electric suburban railways where the income is largely derived from passenger receipts, the future possibilities of freight traffic over these lines makes a low gradient desirable whenever possible.

50. Coefficient of adhesion expresses the ratio between tractive effort and weight on drivers. Coefficient $= \dfrac{F_e}{W}$.

This is expressed in per cent and is a variable depending upon the condition of track and composition of wheels, the following values are approximate.

51. Coefficients of Adhesion with Uniform Torque.

Clean dry rail	30 per cent.		
Wet rail	18 "	with sand	22 per cent.
Rail covered with sleet	15 "	" "	20 "
Rail covered with dry snow	10 "	" "	15 "

52. It is **good practice to design the motive power** of a car or locomotive so that it can **slip the wheels on a dry rail,** this practice not being strictly followed in very high speed motor car equipments, owing to the enormous current input this would demand of such an equipment designed primarily for low tractive effort and high speed. In locomotive practice however, it is customary **to rate the locomotive** at the **tractive effort** corresponding to a coefficient of 22 per cent of the weight upon the drivers, that is, at practically the slipping point of the drivers. This practice is handed down from steam locomotive practice where the tractive effort is fluctuating during one revolution of the driver, hence on account of the perfectly uniform torque exerted by the electric motor, the electric locomotive could readily be rated some 15 per cent higher in tractive effort for the same weight upon the drivers.

53. The **values for coefficients of adhesion** given in the Table (**51**) are based upon the assumption that the motive power gives a perfectly uniform torque. Thus, while 30 per cent is the maximum value given, tests with electric locomotives have recorded as high a coefficient as 35 to 40 per cent under very favorable conditions. For single motor-car service where all axles are equipped with motors, the tractive effort available with a coefficient of adhesion of 22 per cent is 22 per cent of 2000 = *440 lb. per ton, or sufficient* to carry the car up a 22 per cent grade, taking

no account of train resistance or reduced effective weight of car or an extreme grade. A motor car, however, has to operate under all cli conditions and hence is liable to meet conditions where the coeffici adhesion may drop to as low as 10 per cent, so that the **maximum** in **practice** should never exceed 12 to 13 per cent, and should su treme grades be necessary, some form of **track brake** should be pr as an auxiliary to hand or air brakes to ensure safety in operation. over, all curves encountered should be compensated where grad heavy, especially if the rigid wheel base of the trucks is large and the of curvature small.

54. Where **trailers** are hauled, it becomes important to know **maximum grade** can be surmounted with the tractive effort per by different coefficients of adhesion. In Fig. 16 is shown the relati tween per cent of total train weight on the driving wheels to the pe grade that can be surmounted when a flat allowance of 10 lb. per made for train resistance.

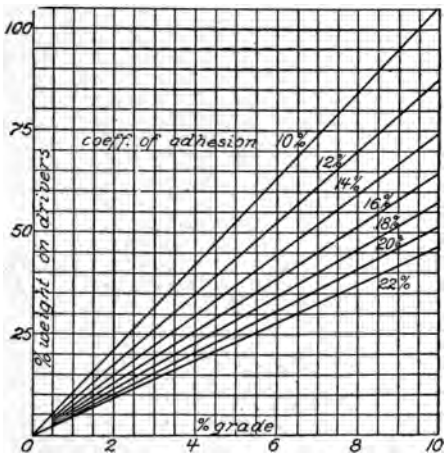


FIG. 16.—Relation between per cent weight on drivers and per cent g

Example: A motor car weighing 36 tons, all axles equipped with m hauls a trailer weighing 24 tons, what maximum grade can it asce

Answer: Total train weight $36+24 = 60$ tons.

$$\text{Weight on drivers} = \frac{36}{60} = 60 \text{ per cent.}$$

Hence from Fig. 16, train can ascend a 9.3 per cent grade with cent coefficient, or with adverse rail conditions, a grade of 5.7 pe with a coefficient of 10 per cent.

55. The values in Fig. 16 provide no leeway for **starting on** A minimum of 10 lb. per ton is required for starting freight train an additional 4 lb. per ton for train resistance, hence, total tractive on grade.

Tractive effort per ton $= 4+10+(20 \times \text{per cent grade})$.

56. Based upon above formula, Fig. 17 is made up giving the **weight of locomotive required to operate trains** from 500 to 3000 tons gross weight on any grade. It is assumed that all the locomotive weight is on the drivers, an assumption that may hold true in slow speed freight service if the alignment is good. Where pony or bogie guiding trucks are necessary for safety in rounding curves or to prevent nosing, divide the values of locomotive weight as obtained from Fig. 17, by the percentage of weight on drivers to total locomotive weight obtaining in the design of locomotive required.

SPEED-TIME CURVES STRAIGHT LINE FUNCTIONS.

57. The many **problems connected with train acceleration** can be treated either analytically or graphically. As will be shown later, there are so many variables entering into the consideration of train movements at variable speeds that the analytical method becomes somewhat complicated and difficult to follow. The graphical method is equally as accurate, much easier to work with, and the final results are given in such

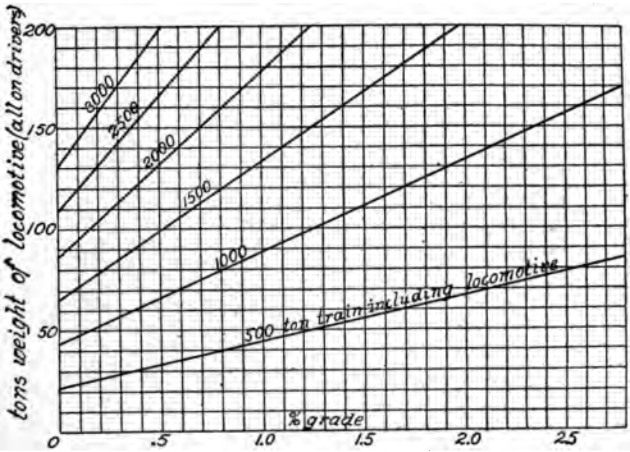


FIG. 17.—Hauling power, electric locomotives.

form that they are of general application without calling for the familiarity of terms and symbols made necessary by the analytical treatment. Through out this work therefore, the graphical method will be used and only such fundamental formulas given as are indispensable.

There are several terms used in connection with train acceleration phenomena which are defined herewith.

58. Tractive effort, being the torque in pounds developed at the rim of the wheels divided by total train weight in tons. This term is usually expressed in pounds per ton of train weight and includes train resistance losses.

59. Braking effort, also expressed in pounds per ton and being the opposite of tractive effort, expresses tne force tending to retard the motion of the train and bring it to rest.

60. Rate of acceleration, being the increment expressing the rate of **increase** in speed of train and may be expressed in feet per second per sec., or miles per hr. per sec.—usually the latter.

61. Rate of braking, being the increment expressing the rate of **decrease** in speed of train. Both rate of acceleration and rate of braking may vary considerably during successive periods of time, depending upon type of motive power and brake rigging used.

62. Train resistance, a variable, expressed in pounds per ton and tending to retard the motion of the train (see **32, 38**).

63. Speed-time curves, expressing the relation of the above variables in curve form, generally with speed in miles per hour as ordinates and elapsed time in seconds as abscissae.

64. Energy curves, showing the energy consumption, generally expressed as watt-hours per ton mile for different rates of acceleration, braking and train resistance for various elapsed times over a given distance run.

65. A better understanding of the possible movements of a car or train operating at different speeds over different distances, is obtained by eliminating the type of motive power and brake rigging used, and assuming straight line acceleration, coasting and braking curves. The results so obtained are fundamental, and may be applied to examples using any type of motive power with a correction factor entered into later, known as the efficiency of acceleration.

66. The problem of train acceleration deals with the movement of a given weight over a given distance within a specified time. As it is im-

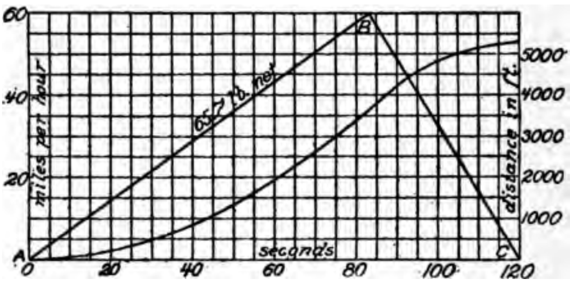


FIG. 18.—Typical speed-time distance curve (no coasting).

practicable to instantaneously start and stop the train, it is necessary to deal with some finite rate of acceleration and braking, thus giving rise to the simple form of speed time curves shown in Fig. 18. The speed-time curve is here shown in the simplest form, acceleration being carried on at constant rate up to the point of applying brakes, which are so applied as to also give a constant rate of braking. The area enclosed within the triangle, A, B, C, is proportional to the distance travelled, the distance covered up to any instant being represented by the distance-time curve shown. Thus, with the constants chosen in Fig. 18, a maximum speed of 60 miles per hr., is required to obtain an average speed of 30 miles per hr., that is, covering a distance of 5280 feet in 120 seconds.

67. The simple **formulas required in the construction of fundamental speed-time curves** are given as follows:

Let s represent velocity in feet per second;

f, the force producing acceleration expressed in lb. per ton;

t, the time interval;

m, the mass $\left(m = \frac{w}{g} = \frac{w}{32.2}\right)$, and

w, the weight in lb.

Then
$$s = \frac{f\,t}{m}$$
$$= \frac{f\,t\,g}{w}.$$

Expressing w in tons, $s = \dfrac{32.2\,f\,t}{2000}$,

Then $s = .0161\,f\,t.$

It is more convenient to express velocity in miles per hr

Hence $S = .682\,s$, in miles per hr.

And substituting $s = .01098\,f\,t.$

The distance covered in any given time may be expressed

$$L = \frac{f\,t^2}{2\,m}$$
$$= \frac{f\,t^2 \times 32.2}{2 \times 2000}$$
$$= .00804\,f\,t^2.$$

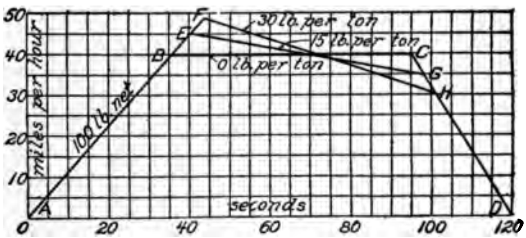


FIG. 19.—Typical speed-time curves (varying coasting resistance).

68. In practical operation it is not possible to choose the rate of acceleration and braking with such niceness as shown in Fig. 18, a greater or less period of coasting being required. **Introducing coasting** gives rise to the form of speed-time curve shown in Fig. 19, showing three friction rates—F = 0, 15 lb. per ton, and 30 lb. per ton respectively. With no friction the speed-time curve, A, B, C, D, is constructed, the speed being maintained constant at 40 miles per hr. during the coasting period. With 15 lb. per ton friction, the speed-time curve, A, E, G, D, is formed, and with 30 lb. per ton friction the speed-time curve, A, F, H, D. The introduction of friction occasions a falling off of speed during the coasting period proportional to the friction value taken, which for the sake of simplicity is here assumed to be constant at all speeds.

69. The **speed-time curves** shown in Figs. 18 and 19 both indicate the completion of the run of 5280 ft. in 120 seconds, although in one case the rate of acceleration was that produced by 65.7 lb. per ton, and in the other case by 100 lb. per ton. These curves are of equal area, as the distance in each case is 5280 ft., and it thus becomes possible to produce any number of speed-time curves for a given distance and elapsed time by varying the rate of acceleration with consequent variation in time of coasting.

70. A more extended set of curves is given in Fig. 20, for the same distance of one mile covered in 120 seconds, the rate of acceleration varying from 0.713 miles per hr. per sec. as a minimum to an infinite number of miles per hr. per sec. as a maximum.

A train resistance value of 15 lb. per ton is assumed constant at all speeds and the dotted curve, A B, is the loci of the maximum speeds reached

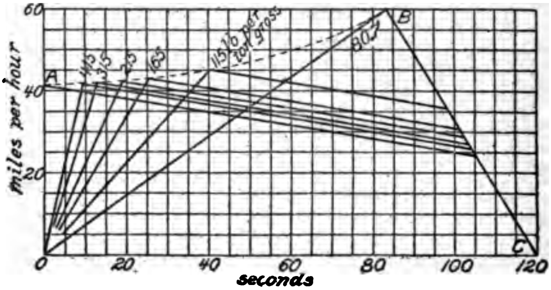


FIG. 20.—Typical speed-time curves (varying accelerating rates).

with the different rates of acceleration. The highest maximum speed required is obtained with no coasting, and the minimum speed is obtained with an infinite rate of acceleration. The pounds per ton corresponding to the different accelerating rates are given as including 15 lb. per ton train resistance, hence the net tractive effort values corresponding to the rates of acceleration indicated are 15 lb. per ton less than the figures given.

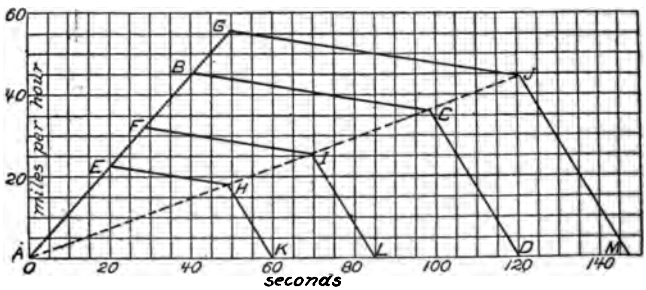


FIG. 21.—Similar speed-time curves (varying distances).

71. Instead of plotting similar curves for distances other than 5280 ft. advantage may be taken of the fact that the **area enclosed by the speed-time curve** is proportional to the distance travelled and the co-ordinates are proportional to the square root of the enclosed area. It is convenient therefore to plot a full series of curves for one distance, preferably one stop per mile, that is, a distance of 5280 ft. run, and apply the results so *obtained for any other* distance by using a factor expressing the relation

of the square roots of the distance travelled. This is shown in Fig. 21, where A, B, C, D, represents an area of one mile, or one stop per mile; A, F, I, L, two stops per mile with a factor of $\frac{1}{\sqrt{2}} = .707$; A, E, H, K, four stops per mile with a factor of $\frac{1}{\sqrt{4}} = .5$, and A, G, J, M, one stop in one and one-half miles with a factor of $\sqrt{1.5} = 1.225$.

72. Referring to Fig. 20, it is obvious that a similar sheet could be prepared for any elapsed time other than 120 seconds, using the same train resistance and braking values of 15 and 150 lb. per ton respectively.

73. Fig. 22 is constructed to show the **time limits imposed by** 15 lb. per ton **train resistance,** and 150 lb. per ton braking for any length of

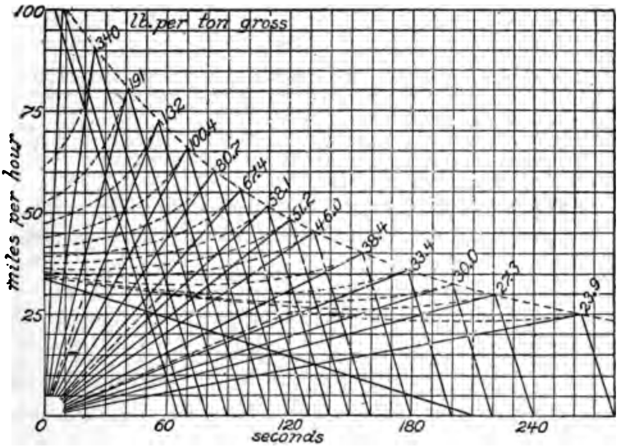


FIG. 22.—General speed-time curves (train resistance 15 pounds; braking 150 pounds).

run and any rate of acceleration. The dotted curves indicate the loci of the several maximum speeds reached with different accelerating rates for a run made in a given elapsed time, thus the dotted curve terminating at 80.7 lb. per ton is a reproduction of the similar dotted curve, A B, given in Fig. 20, and gives the maximum speed reached with any rate of acceleration for a run of 5280 feet in 120 seconds with 15 lb. per ton train resistance and 150 lb. braking effort. Similarly, the dotted curve terminating at 100.4 lb. per ton gives the limiting maximum speeds reached with any rate of acceleration when a run of 5280 feet is accomplished in 110 seconds with the same values of train resistance and braking, etc.

74. By the use of Fig. 22, it becomes possible to determine the **time required to make a run over any distance with any rate of acceleration,** provided the train resistance is 15 lb. per ton and braking corresponds to 150 lb. per ton retarding effort.

Example: Given a distance of 8000 ft., train resistance 15 lb. per ton, braking effort 150 lb. per ton, tractive effort gross 67.4 lb. per ton (for

cluding 15 lb. per ton train resistance), what is the minimum time required to perform the run and what maximum speed is reached?

Answer: From Fig. 22, minimum elapsed time with 67.4 lb. tractive effort = 130 seconds with no coasting.

$$\text{Ratio of distances} = \sqrt{\frac{8000}{5280}} = 1.23.$$

Hence for 8000 ft. time of run = 130x1.23 = 160 seconds.

Maximum speed for 5280 ft. = 55.6 miles per hr.

Hence for 8000 ft. speed = 55.6x1.23 = 68.5 miles per hr.

75. **In actual practice,** a certain amount of **coasting** is necessary; hence, the run of 8000 ft. would be made in somewhat more than the minimum possible limit of 160 seconds, or else the tractive effort should be increased to allow for a higher rate of acceleration that would permit of some coasting. Fig. 22 is of universal application as it is not limited to any particular type of motive power, having its own peculiar speed characteristics. Moreover, the values of 15 lb. and 150 lb. chosen for train resistance and braking effort respectively are conservative operating values obtaining in practice.

76. As will be discussed later, **the maximum speed reached during the performance of a service run** will be little influenced by the type of motive power and its curve characteristics. The values indicated in Fig. 22 will hold approximately true in service operation with series motors of either the a.c. or d.c. type, and hence, the curves given constitute a set of fundamental data by means of which it becomes possible to attack any acceleration problem and determine the several data required.

SPEED-TIME CURVES; MOTOR CHARACTERISTICS.

77. **Electric motors used in railway service** are of the following types:

(1) Series wound d.c. motors,
(2) Single-phase a.c. motors,
(3) Three-phase a.c. induction motors.

In addition to the above, there have been several attempts at operating shunt-wound d.c. motors, but as such motors have not come into even partial use, owing to the superior qualities of other types, the shunt-wound motor will not be discussed.

78. **The d.c. series motor** has the general characteristics shown in Fig. 23.

Applying this **motor characteristic to the performance of a car,** it becomes necessary to reduce the motor voltage during the starting or accelerating period of the car in order to limit the tractive effort to a value that will not slip the driving wheels. In other words, if full voltage was to be applied to the motor at standstill, the resulting current would be enormous, would produce a torque that would slip the wheels, and would far exceed the safe commutating capacity of the motor. Hence, the necessity of introducing external starting resistance in successive steps during acceleration, with the result that the starting current is maintained practically constant at the full load rating of the motor.

79. In Fig. 24 is shown a **speed-time curve with a d.c. series motor,** indicating a constant current input up to a speed of 28 miles per hr., beyond which speed the motor has full voltage applied to its brushes, and hence, operates at a constantly decreasing current until full speed is reached, when current and tractive effort both become constant.

80. **The method used to plot a speed-time curve from a motor characteristic** may be either to take a small speed or time increment, and plot by the step-by-step method or by the more accurate method proposed by Mailloux in Proceedings American Institute of Electrical *Engineers,* June 1902. Where a large number of speed-time curves are

to be plotted from a single motor characteristic, Mailloux's method is as quick and more accurate than any other, but where miscellaneous motor characteristics must be used the step-by-step method gives a quicker approximation that is sufficiently accurate for practical purposes.

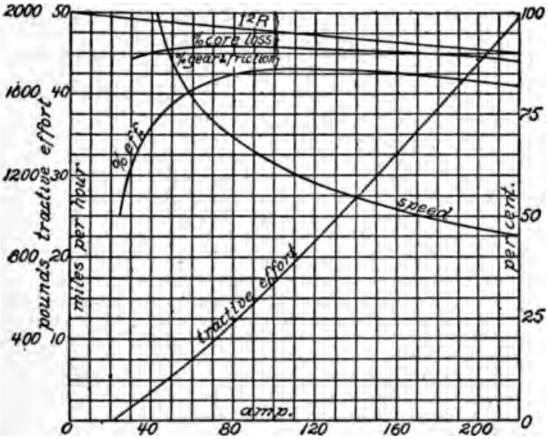


FIG. 23.—Typical d.c. motor performance (75 hp., 500 volts).

81. As many acceleration problems involve curves of rather short radii and grades, requiring a step-by-step method of plotting the performance of a train in operation, any **general speed-time curves,** other than straight line functions (Fig. 22), would not be of universal application; especially

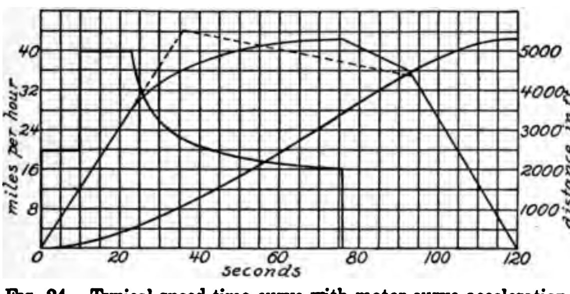


FIG. 24.—Typical speed-time curve with motor-curve acceleration.

as considerable variation exists in the characteristics of railway motors in general use. The straight line functions give sufficiently close approximation as regards maximum speed, rate of acceleration and general constants required to perform a given schedule as indicated in Fig. 24, comparison of straight line and motor characteristics.

82. The a.c. series motor must operate at a lower flux density than its d.c. competitor and hence has a motor characteristic that is even more drooping than that of the d.c. series motor. In consequence, there is less straight line and more motor curve running during the accelerating period, resulting in a lesser peak load demand upon the distributing system. Thus, while constant rate of acceleration with d.c. motors may be carried up to 60 per cent. of the free running speed, this ratio may be reduced to 40 per cent. with the a.c. motor.

The **maximum speed attained during the performance of a service run**, however, will be practically the same for either type of motive power, and a preliminary speed-time run may be deduced from Fig. 22, straight line characteristics.

83. The three-phase induction motor is practically a constant-speed motor, its speed dropping only approximately 12 per cent. from no load

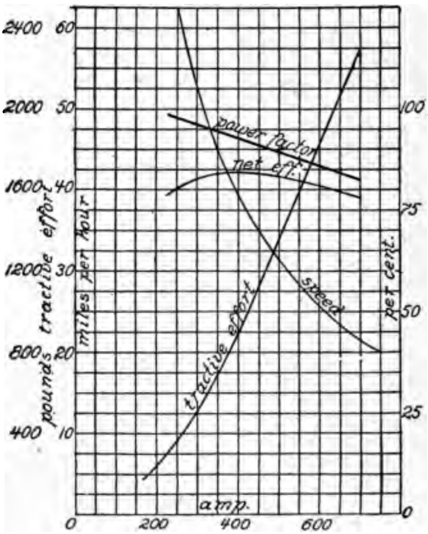


Fig. 25—Typical a.c. motor performance (75 hp., 225 volts).

to maximum tractive effort developed. During the accelerating period therefore, this type of motive power labors under the disadvantage of demanding full rate of acceleration carried up to full free running speed, a condition calling for a very large peak load as compared with either d.c. or a.c. series motor performance.

Owing to its general unfitness for rapid transit service with frequent stops, the induction motor is limited to long distance running as its legitimate field.

84. The rate of acceleration permissible is determined first by comfort of passengers and second by the tractive effort availab'e. It has been found experimentally that the discomfort to passengers is o casioned largely by the change in rate of acceleration and not entirely upon its intensity. Thus, a very high rate, two miles per hour per second, may occasion no discomfort with cars having cross seats, provided the rate is attained

gradually with no abrupt change. The following accelerating rates obtain in practical operation.

85. Accelerating Rates.

LOCOMOTIVES.

Steam locomotives,	freight service	0 1 to 0.2	miles per hr.	per sec
" "	passenger "	0.2 to 0.5	" "	"
Electric "	" "	0.3 to 0.6	" "	"

MOTOR CARS.

Electric motor cars	interurban service	0.8 to 1.3	miles per hr.	per sec.
" " "	city "	1.5	" "	"
" " "	rapid transit "	1.5 to 2.00	" "	"
Highest practical rate		2.00 to 2.5	" "	"

86. The above rates apply only to that part of the accelerating period during which the current is maintained practically constant by means of cutting out successive sections of the external starting resistance. The higher rates from 1.0 to 2.5 miles per hr. per sec. demand a gradual increase to those values in order to avoid the discomfort to passengers that would surely result from a sudden application or cessation of such rates.

The **coefficient of adhesion** also **determines** the **accelerating rate** by limiting the available tractive effort, thus giving rise to the values given above for locomotive practice. As the practice is common to run locomotives very close to the limit of adhesion for full speed operation, it leaves but a small excess of tractive effort available to accelerate the train. High acceleration demands that all axles shall be equipped with motors, and if trains are run, that all cars must be motor cars, that is, no trailers are permissible when extreme accelerating rates are required to make the schedule desired.

87. The limits reached in acceleration hold equally true in braking. As a matter of fact, acceleration may be at a higher **rate** than **braking**, for two reasons:

First. Discomfort to passengers is greater during braking of cross-seat cars, as the inertia of the passenger tends to carry him away from his seat and he lacks the supporting back that prevents discomfort during rapid acceleration when his body is pressed backward,

Second. In braking a train to standstill, it is necessary for the operator to stop within a distance of a few feet of a fixed spot, and the skill shown in judging speed and distance will determine the braking rate. During acceleration no such limit exists; the motorman has absolute freedom: in fact, it is becoming the custom to adopt a system of motor control that will permit of uniform or automatic acceleration, the rate being determined by the necessities of the service.

88. The inertia of revolving parts must be considered and the effect is to reduce the effective accelerating and braking rates. In other words, it is necessary to expend from 4 to 12 per cent more tractive effort during acceleration and braking in order to overcome the inertia of car wheels, gears and motor armatures, than is required to accelerate the car or train longitudinally on a level track. This inertia is usually considered as extra weight and is calculated as follows:

$$\text{The energy of a rotating body} = W \div g\, s^2$$

$$= W \div g \frac{r^2}{R^2} S^2;$$

Where s = the speed of the center of gravity of the body in feet per sec.
S = speed of train,
r = radius of gyration,
R = radius of rim,

or the effective weight $= \dfrac{W\, r^2}{R^2}$.

The ratio $\frac{r^2}{R^2}$ has been found from a large number of tests to be approximately 0.6 for ordinary designs of car wheels. The ratio, $\frac{r^2}{R^2}$, for armature is approximately 0.5. For geared motors it is important that allowance be made for the higher speed of the armature.

Hence the effective weight of the armature

$$=0.5\left(\frac{\text{dia. of arm.}}{\text{dia. of wheel}}\times\text{gear ratio}\right)^2\times\text{weight of armature.}$$

Per Cent of Total Tractive Effort Consumed in Rotating Parts.

Electric locomotive and heavy freight train	5 per cent.
" " " high speed passenger trains	7 "
" high speed motor cars	7 "
Low speed motor cars	10 "

89. In figuring upon accelerating and braking problems for different classes of service, the above percentages should be added to the actual train weight to get the **effective train weight.** The net tractive effort as determined by the gross tractive effort minus the train resistance can then be used in connection with the effective train weight to get the rate of acceleration as expressed in miles per hour per second.

90. Schedule speed, expressed in miles per hour, denotes the average speed of a train including all stops, slow downs, etc., being the distance run in miles divided by the elapsed time in hours including time of stops enroute. The duration of stop varies approximately as follows for different classes of railway service.

91. Duration of Service Stops.

Through trains, steam	5 minutes
Local " "	2 "
Interurban cars, electric	10 to 30 seconds
City rapid transit trains, electric	10 seconds
City surface cars, electric	7 "

The following frequency of stops are characteristic of the different classes of railway service:

92. Frequency of Stops in Service.

Steam locomotive through service	1 stop in 100 miles.
" " local "	1 stop in 20 miles.
" " suburban "	1 stop per mile.
Electric interurban express	1 stop in 10 miles.
" " local	1 stop in 2 miles.
" suburban	1 to 2 stops per mile.
City elevated or rapid transit	2 to 3 stops per mile.
City surface lines	5 to 10 stops per mile

93. The **relation** obtaining **between schedule and maximum speed with varying frequency of stops** is expressed in Fig. 26, which indicates the schedule speed possible to make with trains having a free running speed of 30, 45, 60 and 75 miles per hr. respectively.

Thus with a train geared for a free running speed of 60 miles per hr. it is possible to make a schedule of 45.5 miles per hr. with one stop in four miles, 37.5 miles per hr. with one stop in two miles, etc.

For frequent stop service a low free running speed is desirable as it is easier on the equipment, calls for less motor capacity and less energy consumed in performing the service. Hence, **use the lowest maximum speed that will give the schedule desired.**

When using Fig. 26, it should be recognized that where stops are more frequent than one per mile, the rate of acceleration becomes a controlling factor, and as shown in the curve, when the frequency of stops approaches

three or more per mile, the maximum free running speed of the equipment does not have any appreciable effect upon the possible schedule speed. Hence, for frequent stop service where it is of great importance to attain the highest possible schedule speed, recourse should be had to Fig. 22, in order to determine the advantages of higher rates of acceleration than the 120 lb. gross which forms the basis of Fig. 26.

94. In all classes of service, due recognition should be paid to the **effect of curves of** such **short radii** as to demand slowing down while rounding them. The safe speed at which a curve may be taken will depend upon the **elevation of the outer rail,** but a greater elevation than eight inches is not common. Also curves having a spiral approach will ride much easier than those in which the tangent leads directly into the curve.

95. Safe Maximum Speed on Curves.

Radius of Curve, ft...	10,000	5,000	2,000	1,000	500	200	100	50
Speed, Miles per hr....	100	75	50	35	25	15	10	6

The above values apply only when full elevation may be given outer rail and speeds will be less when operating in city streets where such eleva-

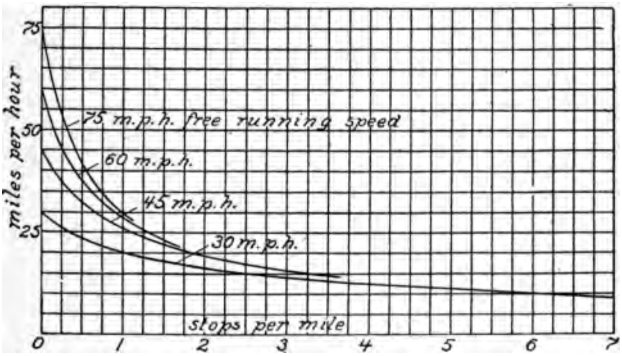


FIG. 26.—Relation between maximum and schedule speed and stops per mile.

tion is not possible, and where wheel flanges of three quarters of an inch or less are the rule.

96. Hence, on any road abounding in curves of short radius, it will not be possible to reach the schedules given in Fig. 26. No general rule can be given to fit all cases, as each problem must be treated according to local conditions. There is sufficient leeway in the schedules given in Fig. 26 to **allow for irregularities of stops,** as there is included a period of 10 seconds coasting that may be cut out when a stop has exceeded the limit of 15 seconds assumed, but excessive duration of stops and time lost in meeting and passing trains on single track system is not allowed for.

ENERGY AND POWER CONSUMPTION.

97. The **energy consumed in moving a train** at constant speed is expended in overcoming train resistance (Figs. 9 to 13 inclusive) and internal motor losses. It is customary for manufacturers to give the net efficiency of railway motors after having carefully determined their internal losses from stand tests, and hence, the railway operator is concerned only with the determination of the energy required to overcome train resistance when the speed of the train is constant at any fixed miles per hr.

98. Curves given in Figs. 9 to 13 inclusive express in pounds per ton the **train resistance** of different weights and combinations of cars. As a ready means of changing from pounds per ton to watt-hours per ton-mile, the following holds approximately true:

$$\text{Pounds per ton} \times 2 = \text{watt-hours per ton-mile.}$$

The above gives the watt-hours per ton-miles net output of the motive power, and to get train kilowatts input it is necessary to know the efficiency obtaining for different sizes of equipments as given by the manufacturers.

99. Efficiency of Railway Motors.

Capacity hp.	30	40	60	80	100	125	150	200	250	*250	*500
Max. Efficiency, per cent.	83	84	86	87	88	88	89	89	89	91	93
Efficiency Car, full speed, per cent.	65	68	70	72	73	74	74	75	75	90	92

100. The **maximum efficiency of railway motors** of the geared type occurs during maximum output and hence, the values quoted should be used for calculation of power required to accelerate a car or train. An exception to this rule may be taken in locomotive work, where it is customary to force the motors to nearly their maximum rated output even after train has reached its normal maximum speed.

101. The **efficiency** when **car** is **at full speed** is generally lower with motors of the geared type, owing largely to the losses in gears and also in the magnetic circuit of the motors themselves. This lower efficiency at higher speeds does not hold true of motors of the gearless type as indicated in Table **99**. The advantage of using gearless motors for high speed passenger service is clearly indicated by the extremely high efficiency at light outputs. On the other hand, such motors do not show up favorably with the geared type for heavy freight haulage as the efficiency falls off rapidly at the overloads characteristic of this class of service.

102. To determine **power required to propel a car or train** at any constant speed, proceed as follows:

$$P = \frac{F \times 2 \times W \times S}{\eta \times 1000}, \text{ in kw.,}$$

wherein F is the train resistance (from Figs. 9 to 13 inclusive); W the weight of car or train in tons (2000 lb.); S the speed of train in miles per hour, and η the motor efficiency with train at full speed.

103. The following **tables** have been computed **showing the kilowatts input** required **for motor-car trains,** and also for **high-speed passenger** and **low-speed freight** train operation. These tables are based directly upon the train resistance values given in Figs. 9 to 13 inclusive, and represent the kilowatts input that would be expected with well ballasted rail when trains are running at constant speed.

104. Constants assumed in Table **105** are· efficiency at full speed, **75** per cent. based upon the use of d. c. geared motors; and

Train resistance as obtained from formula

$$\text{Tractive effort} = \frac{50}{\sqrt{W}} + .03\,S + \frac{.002\,a\,S^2}{W}\left(1 + \frac{n-1}{10}\right).$$

Cross-sectional area of cars is as follows:—20-ton car, cross-section, **90** square feet; 30-ton car, cross section, 100 square feet; 40-ton car, cross-section, 110 square feet; 50-ton car, cross-section, 120 square feet· 60-ton car, cross-section, 120 square feet.

* *Motors of gearless type.*

105. Kilowatts Input at Train Constant Speed Running on Tangent Level Track. (see 104).

MOTOR-CAR SERVICE.

Speed in Miles per Hour	10	20	30	40	50	60	70	80	90	100
Train Weight			SINGLE-CAR TRAINS							
20 ton car	6.5	16.2	32.0	56.7	93.5					
30 " "	8.0	19.5	38.4	67.3	109.0	167				
40 " "	9.4	23.1	44.1	76.2	124.0	188	276			
50 " "	10.4	25.6	49.2	84.8	137.0	210	305	430	584	
60 " "	11.5	27.9	52.8	90.2	144.0	218	316	442	599	792
Train Weight			TWO-CAR TRAINS							
2-20 ton cars	9.3	22.4	42.5	72.5	116.					
2-30 " "	11.5	27.4	51.4	87.0	137.	206				
2-40 " "	13.2	31.6	59.0	99.3	156.	234	336			
2-50 " "	14.8	35.5	66.3	111.0	175.	261	374	520	699	
2-60 " "	16.3	38.8	71.7	119.0	185.	274	390	540	720	945
Train Weight			THREE-CAR TRAINS							
3-20 ton cars	11.4	27.2	50.9	84.1	136.					
3-30 " "	14.0	33.3	61.8	103.0	162	240				
3-40 " "	16.3	38.7	71.5	119.0	185.	271	391			
3-50 " "	18.4	43.7	80.6	134.0	206.	308	437	602	805	
3-60 " "	20.1	48.0	87.4	144.0	222.	326	460	635	925	1092
Train Weight			FIVE-CAR TRAINS							
5-20 ton cars	14.8	35.3	65.4	109.	171.					
5-30 " "	18.3	43.5	80.0	133.	205.	303				
5-40 " "	21.3	50.8	93.2	154.	237.	348	493			
5-50 " "	26.2	61.9	112.0	183.	279.	406	568	773	1026	
5-60 " "	31.3	72.8	130.0	208.	312.	448	622	835	1100	1415

106. Kilowatts Input at Train, Constant Speed Running on Tangent Level Track. (See 107.)

LOCOMOTIVE PASSENGER SERVICE

Speed in Miles Per Hour	10	20	30	40	50	60	70	80	90	100
Gross Train Weight										
200 tons	17.5	41.2	75.8	124	196	277	398	530	710	920
300 "	26.1	60.5	108.0	172	258	369	511	689	905	1160
400 "	32.0	79.0	139.0	219	330	462	635	840	1100	1405
500 "	41.0	99.0	170.0	268	395	563	755	995	1295	1645
600 "	50.0	118.0	203.0	315	464	645	875	1150	1489	1890
700 "	59.0	135.0	235.0	363	530	735	996	1305	1682	2132
800 "	69.0	154.0	267.0	410	596	828	1117	1460	1878	2375
900 "	77.0	173.0	300.0	459	663	920	1238	1615	2070	2620
1000 "	85.0	193.0	330.0	507	730	1011	1358	1771	2261	2860

107. Constants Assumed in Table **106** are: efficiency at full speed, 90 percent. for locomotive using series d. c. motors of the gearless type; cross section of locomotive 120 square feet; cross section of cars 110 square feet; weight of cars 50 tons, and track rail to weigh not less than 80 lb. per yard.

108. Kilowatts Input at Train, Constant-Speed Running on Tangent Level Track (see 109).

LOCOMOTIVE FREIGHT SERVICE

Speed in Miles per Hour	10	20	30	40	50
Gross Train Weight, Tons.					
500	46	105	180	284	418
1000	91	205	350	540	773
1500	137	308	520	795	1130
2000	180	405	688	1050	1490
2500	225	505	855	1305	1845
3000	270	605	1022	1560	2210

109. Constants Assumed in Table **108** are: efficiency at full speed, 85 per cent for series d. c. motors of geared type; cross-section locomotive 90 to 100 square feet; cross-section cars 90 square feet, and weight of cars 40 tons.

110. The above values of power required to drive a car at any speed, apply only for constant speed on tangent level tracks. On up grades there is required an additional tractive effort of 20 lb. per ton for each one per cent grade (see **46**). Hence, to calculate **power required on grades,** proceed as follows:

The total train resistance is $F_o = F + F_g$, in lb. per ton; wherein F is the train resistance in lb. per ton found from the curves, and F_g the tractive effort due to the grade (F_g = per cent grade ×20). Then the power input is

$$P = \frac{2\,W\,F_0\,S}{1000\,\eta}, \text{ in kw.,}$$

wherein W is the weight in tons of the train; F_0 the total train resistance in lb. per ton; S the speed in miles per hr., and η the efficiency of the motors.

Example: Given a train of three 40-ton cars operating up a two per cent grade at 40 miles per hr., what kilowatt input is demanded by the motors?

Answer: From Fig. 11, a three-car train requires a tractive effort of 9 lb. per ton at 40 miles per hr.

To this add for grade 2x20 =	40 lb. per ton,
Tractive effort from Fig. 11 =	9 lb.
Total tractive effort	49 lb.
Train weight = 3x40 = 120 tons.	

For motor efficiency use 80-hp. motors operating at a *maximum* efficiency of 87 per cent as the excessive output demanded by the grade will increase the load on motors to nearly full-load value.

$$\text{Hence input} = \frac{2 \times 120 \times 49 \times 40}{1000 \times 0.87} = 540 \text{ kilowatts.}$$

111. The above power values are based upon the assumption that the train has reached full speed and the power values are those required to maintain the train at constant speed. During the time that the train is attaining full speed, however, it is necessary to impart to it the **energy required to accelerate** the mass in the direction of travel and also to accelerate the rotating parts around their several axes.

$$\text{Energy of acceleration} = \frac{ms^2}{2} = \frac{ws^2}{2g},$$

wherein w **is the weight in pounds;** s **the velocity in ft. per second, and** g **the gravity constant (32.2 feet per second per second).**

112. In addition to the energy of acceleration, it is necessary during the accelerating period, to furnish power to the train to overcome train resistance, a quantity constantly changing with increasing speed, and finally to supply various changing losses in the motive power and its system of control. The straight line diagram furnishes the simplest means of attacking the **speed-time problem,** and it also furnishes the fundamental data for all energy consumption curves, as it eliminates the question of motive power with its internal losses, and considers only the moving train itself.

The energy required to move a train from rest to a given velocity is represented by

$$\frac{ms^2}{2} + F_0 L,$$

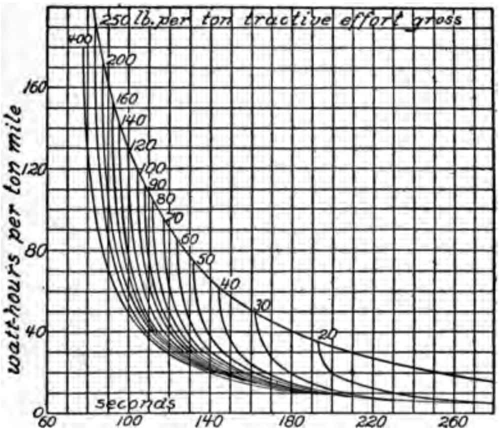


FIG. 27.—Energy consumption (train resistance equals 0).

wherein m is the mass; s the velocity in ft. per second; F_0 the total train resistance in lb., and L the distance in feet covered.

113. The **most convenient form of expressing energy values** is in watt-hours per ton-mile, and Fig. 27 has been constructed from the speed-time data in Fig. 22, giving the energy consumption for any rate of acceleration and elapsed time for a distance of 5280 feet or one mile run. This set of curves is plotted with train resistance = 0 and hence, represents the value of the energy of acceleration only.

114. In bringing a train to rest by means of brakes, the **energy stored in the train** during acceleration and represented by $\frac{ms^2}{2}$ is all wasted in heating the wheels and brake shoes, and the values in Fig. 27 therefore represent the energy thus dissipated as heat. The curves have no value as applying directly to service conditions as all moving trains have more *or less running* resistance, but they are useful as indicating the energy

required to accelerate the mass, all of which reappears as heat in the brake shoes and car wheels, unless some method of regenerative braking be used. At best, however, such regenerative methods are vastly inefficient and the energy values given in Fig. 27 represent the price paid for a high schedule speed coupled with frequent stops.

115. Unless the train reaches a speed of more than 40 miles per hr. it is a sufficiently close approximation for preliminary calculations to assume a constant rate of train resistance of from 10 to 15 lb. per ton, the latter figure being the more conservative value. Hence, Figs. 28 and 29 are plotted with a constant value of train resistance at all speeds of 10 and 15 lb. per ton respectively. These curves used in conjunction with the speed-time curves of Fig. 22, permit of the **complete solution of any acceleration problem** so far as relates to performance of the train and its net energy consumption. For convenience, both speed-time and energy curves are made up with the same elapsed time for a mile run as abscissa, this distance run being chosen as being a convenient basis for comparison.

116. Having determined the **watt-hours per ton-mile for** a mile run the same value holds true for **any** other **distance** run as long as the speed

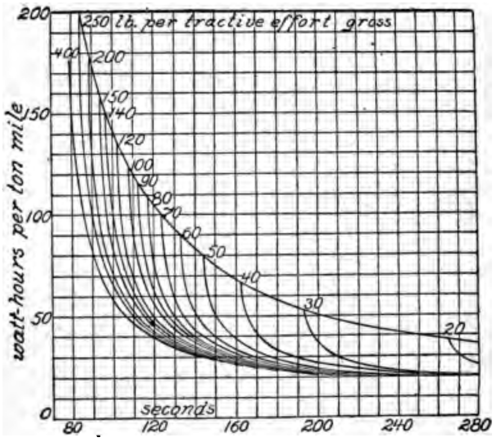


FIG. 28.—Energy consumption (train resistance equals 10 lb. per ton).

time curve is entirely similar in every respect and the areas are proportional to the respective distances run. Thus, a mile performance in 120 seconds with a tractive effort of 90 lb. per ton (including 15 lb.) per ton train resistance) will require an output of the motive power of 73 watt-hours per ton-mile, and the same energy, 73 watt-hours per ton-mile, would be required to perform a run of half the distance in $\frac{1}{\sqrt{2}}$ times 120 seconds, or 84.8 seconds.

Thus while the speed-time curves must be changed in area proportional to the distance travelled, the value of energy consumption found for one distance holds equally true for any other distance made with a similar speed-time curve.

Example: Given a run of 1760 feet to be made in 75 seconds, train weight *100 tons, 33⅓ per cent.* on drivers, coefficient of adhesion 12 per cent., *train resistance 15 lb. per ton.* Find energy consumption.

Answer: Available tractive effort = 200,000x.335x.12 = 8000 lb. = $\frac{8000}{100}$ = 80 lb. per ton.

To reduce to mile basis $\sqrt{\frac{5280}{1760}} \times 75 = 130$ seconds.

From Fig. 29, one mile in 130 seconds with 80 lb. tractive effort gives 60 watt-hours per ton-mile.

The same value, 60, is true for 1760 feet made by similar shaped speed-time curve in 75 seconds.

117. Instead of being able to accelerate a train at a uniform rate until maximum speed is reached, all types of electric motors best operate with a certain amount of **motor curve acceleration** at a rate constantly falling off from the initial or straight line acceleration which is only carried part way to full speed. Also, the electric motor has internal losses, electrical

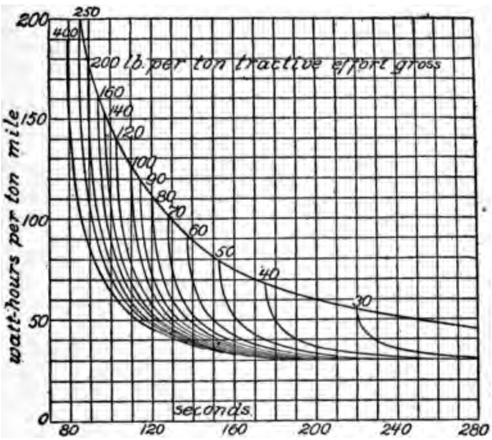


FIG. 29.—Energy consumption (train resistance equals 15 lb. per ton).

and mechanical, which together with certain losses inherent to its system of control makes it necessary to add a greater or less percentage to the net energy consumption curves given in order to obtain the *input* to the train. The different types of motors, a.c., d.c. and induction, all have their distinctive internal losses and type of control, and the performance relation of the several motor equipments to the net energy consumption curves is best expressed by the efficiency of acceleration of the several systems.

118. The efficiency of acceleration is the percentage of the net energy consumption or motor output, to the gross input of the train. The values given in Figs. 28 and 29 hold true as the net output of any type of motor and control system, hence, given the efficiency of acceleration of any system, the net energy values form the basis of calculating train inputs for any operating conditions.

119. The **losses in the motor equipment during acceleration are** divided into:

(1) Internal motor losses including loss in gears.

(2) Losses incident to method of control.

120. Internal motor losses consist of copper I^2R in armature and field, hysteresis and eddy-current losses in the iron circuit, brush-friction and I^2R loss, bearing friction and gear losses. All these losses are included in the curves furnished by the manufacturers for normal 500 volts constant potential at the brushes, but no such values are readily available for fractional voltage operation during the accelerating period.

It is customary to assume full load current of a railway motor during the straight line accelerating period and at standstill the IR drop in the motor copper will approximate 50 volts. It is necessary, therefore, to provide sufficient **starting resistance** in series with the motor to take up the remaining 450 volts or the difference between the line potential and the motor copper drop. This starting resistance is cut out in successive steps as the motor armature gains speed and establishes its own counter electromotive force, until a period is reached when the starting resistance is entirely cut out and the full line e.m.f. is just sufficient to maintain full load current through the motor. This period completes the straight line acceleration, as after this point, the series motor will still accelerate the train, but at a constantly decreased rate, until full constant speed is attained. It is evident then, that a large amount of power is consumed in the starting resistance and to reduce this excessive loss at starting, the method was introduced of connecting two motors in series during half the period of straight line acceleration, thus reducing the amount of starting resistance required.

121. The **series paralleling** of d.c. series motors is in universal operation where two or more motors constitute the car equipment. Where four motors constitute a locomotive equipment, the control is sometimes designed so as to start with four motors in series, change at quarter speed to two motors in series and two in parallel and finally change at half speed to all motors in parallel. Starting with four motors in series is a refinement in control giving such a small increase in economy as to not justify the added complication, hence it is reserved for locomotive work where a low running speed is desirable for shifting purposes.

122. A current input curve is plotted for the three methods of control of d.c. railway motors in Fig. 30, the shaded portion indicating the **energy lost in** heating the **starting resistances** and showing the economy gained by starting with motors in series. This economy is expressed numerically in Table (**123**).

123. Efficiency of Acceleration D. C. Series Motors.

Per cent of Straight Line Acceleration (see **124**)	Motors Parallel Per cent	Two Series Parallel Per cent	Four Series Two Series Parallel Per cent
100	43	56	60.5
90	46	59	62.5
80	49	62	65.0
70	52	64	67.0
60	56	67	69.0
50	58	69	71.0
40	62	71	72.5
30	65	72.5	73.5
20	68	73.5	74.0
10	72	74.5	74.5
0	75	75	75.0

124. The **per cent of straight line acceleration** is the percentage of time constant current is supplied to the total time current is supplied to the motors, and it thus becomes a measure of the shape of the speed-time curve. In typical rapid transit service, the constant accelerating period is from 25 per cent to 35 per cent of the total time power is supplied before coasting and braking begins.

Hence, 100 per cent of straight line acceleration denotes the fact that the cutting out of starting resistance has just been accomplished, while

0 per cent of straight line acceleration is equivalent to saying that the train is running free at full speed at the free running efficiency of the motors.

125. As the two-motor series-parallel combination is of greatest interest, owing to its almost universal adoption, it should be noted that its **efficiency** of acceleration ranges from 56 per cent, to 75 per cent. A typical speed-time curve will require approximately 30 per cent of straight line acceleration, hence, the efficiency of acceleration meeting general operating conditions will be approximately 73 per cent for geared motors of 75 hp. or over and 68 to 73 per cent for smaller motors. The value of 73 per cent efficiency may be used directly in connection with the energy values given in Figs. 28 and 29, that is, the energy curve values divided by .73 will give gross train input watt-hours per ton-mile at the train, allowing for no losses in the distribution system.

Example: Given a mile run made in 135 seconds, tractive effort of 110 lb. per ton including 10 lb. train resistance, find average input for 100 ton train.

Answer: From Fig. 28, energy consumption net = 38 watt-hours per ton mile. Input $= \frac{38}{.73} = 52$ watt-hours per ton-mile.

Train makes 1 mile in 135 seconds = 1 mile in 147 seconds, including 12 seconds stop = 24.5 miles per hr. schedule speed.

Hence, the power input is $P = 52 \times 100 \times 24.5 = 127$ kw.

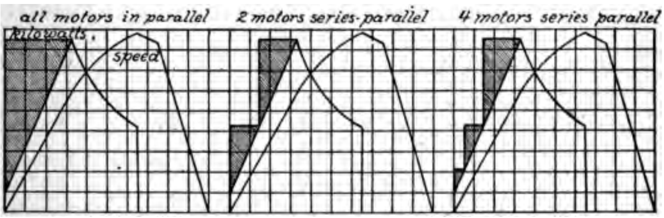


FIG. 30.—D.c. series motor control (shading shows loss in starting rheostat).

126. Table (128) of power input at train **is based upon the relation** given **between schedule speed and frequency of stops.** In other words, an effort has been made to properly proportion the maximum free running speed of the equipment to the proper schedule speed obtaining for a given number of stops per mile. Thus an equipment operating with one stop per mile can make 24 miles per hour schedule with stops of 12 seconds, and should properly be geared for 40 miles per hour. If the equipment was geared for higher maximum speed than 40 miles per hour, the resulting schedule speed would not be much in excess of the 24 miles per hour given, while the power consumption would have been considerably greater. On the other hand, an equipment geared for somewhat lower maximum speed than 40 miles per hour could still make 24 miles per hour schedule with 12 second stops occurring every mile, but requiring a higher rate of acceleration than the 1.1 mile per hour per second assumed. As a high rate of acceleration is undesirable with high speed equipments, the rates given in the table should not be greatly exceeded unless there are strong local reasons making such high rates necessary.

127. Table (128) of schedule speed includes little or no leeway to make up for lost time, and where such interruptions of service are liable to occur they should be classed in the nature of additional stops per mile, and the proper schedule speed, maximum free running speed, etc., should be taken for the *equivalent* number of stops per mile, including actual stops, slow downs for curves, crossings, etc., and a margin for unexpected delays. Thus, with one actual stop of 15 seconds duration occurring every two miles, there may be slow downs for curves, etc., making the equivalent

number of stops approximate one per mile, in which case a 24 mile per hour schedule with 40 miles per hour maximum speed of equipment would be a safer estimate of speed possible than the 32 and 45 miles per hour respectively given for one stop in two miles. In other words, keep the maximum speed of the equipment at the lowest value that will admit of maintaining the schedule desired with the frequency of stops given. Not only is there a saving in energy consumption resulting from the use of lowest possible maximum speed, but as will be shown later, there is also a large saving in the capacity of motor required to perform the service.

128. Train Input in Kw., Frequent Stop Service, Tangent Level Track.

	Stops per Mile									
	1/8	1/4	1/2	1	2	3	4	5	6	7
Schedule speed, miles per hr...	50.0	40.0	32.0	24.0	18.5	15.5	13.7	12.5	11.7	11.0
Maximum speed, miles per hr...	65.0	55.0	45.0	40.0	30.0	25.0	23.0	21.0	20.0	19.0
Stops, seconds...	30.0	20.0	15.0	12.0	10.0	9.0	8.0	7.0	6.0	5.0
Eff. of accel., per cent..........	75.0	75.0	75.0	74.0	72.0	70.0	69.0	68.0	67.0	65.0
Accel., miles per hr. per sec....	.8	.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
The above data are common to all trains.										
Single-Car Operation										
20 ton car........			51	36	29	26	24	23	22	22
30 " "		96	69	51	40	36	33	32	31	31
40 " "	176	119	85	63	51	45	43	41	40	40
50 " "	195	130	94	73	61	55	52	50	49	49
60 " "	200	140	106	82	70	64	62	60	59	58
Two-Car Trains										
2–20 ton.........			78	60	50	45	43	41	40	40
2–30 "		137	104	80	69	64	62	60	59	58
2–40 "	228	160	124	103	89	82	79	77	76	75
2–50 "	255	183	147	125	111	103	99	97	95	94
2–60 "	282	202	165	144	127	117	115	113	111	110
Three-Car Trains										
3–20 ton.........			102	76	67	63	61	60	59	58
3–30 "		173	135	112	97	90	88	86	84	83
3–40 "	280	200	164	140	127	117	115	113	111	110
3–50 "	300	236	198	172	155	145	142	139	137	136
3–60 "	342	263	219	191	175	167	163	160	158	157
Five-Car Trains										
5–20 ton.........			144	124	110	102	98	97	95	94
5–30 "		238	196	171	154	145	142	139	137	136
5–40 "	370	292	246	216	197	188	183	180	178	176
5–50 "	438	350	302	270	250	236	228	225	222	220
5–60 "	495	400	352	314	290	280	275	271	266	263

129. The power values given above for single-car and train operation are based upon the train resistance obtaining with the different weights and combinations of cars, these train resistances agreeing with Figs. 9 to 13.

While the values given in the table cover the entire field of rapid transit service from seven stops per mile to one stop in eight miles, it frequently happens that the relation between maximum and schedule speed given cannot be approximated in actual service operation owing to peculiar local requirements. Thus a suburban car operating at 40 miles per hour maximum may be called upon to operate in city service at terminals or en route where the frequency of stops approximate six per mile, properly calling for a maximum speed of 20 miles per hour. The power consumption given

for six stops per mile would be greatly increased in the case of a high speed suburban car operating on such service, even though series running were adopted exclusively in the city service. Series running would then correspond to the efficiency of acceleration given in (123), for all motors in parallel, and would thus be ten per cent. or more lower than for series parallel operation; hence the figures for kilowatts input at train given in the table represent minimum values resulting from a proper proportion between the maximum free running speed of the equipment, the schedule speed and the frequency of stops.

130. For rates of acceleration other than those given in the table where the frequency of stops is greater than one per mile, any special case should be worked out from the general watt-hour-per-ton-mile curves (Figs. 28 and 29).

No figures are given of power consumption with frequent stop service for electric locomotives, as it is assumed that the legitimate field of the locomotive is in express service having very infrequent stops, in which case the energy of acceleration forms but a small percentage of the total input to the train.

131. The single-phase railway motor, being a series-type motor, can be operated by means of non-inductive external starting resistance as in the case of the d. c. series motor. Owing, however, to the facility of changing a. c. potential by static transformers, a better **method of control** is offered by means of shifting the motor terminals from tap to tap, brought out from the step-down transformer or compensator constituting part of the car equipment. The potential control thus made possible introduces no losses commensurate with the starting resistance losses of d. c. motor control, and is the most efficient form of control yet evolved for railway work.

132. Owing to the fact that the characteristic of the a. c. motor is more sloping than even that of the d. c. series motor, Figs. 23 and 25, the **period of straight line acceleration** will be a lesser percentage of the total time power is supplied the car; that is, the motor-curve running will commence at a lower speed than in the case of d. c. motor operation, thus giving rise to a factor of 20 percent. as the percentage of straight line to the total acceleration period of a typical run. It is thus possible to use a value of 72 percent. as the efficiency of acceleration of an a. c. motor equipment, despite the fact that the single-phase motor car has a free running efficiency but slightly in excess of this.

133. The value of 72 per cent. **efficiency of acceleration** for the a. c. motor equipment includes all losses in the step-down transformer required, and hence the net energy values given in Figs. 28 and 29 when divided by .72 will give the total input at the car for such equipments. Owing to the fact that the single-phase motor is unsuited in itself for continuous rapid acceleration work, its efficiency of acceleration has no considerable operative value, a. c. equipments being used entirely upon roads calling for infrequent stops, that is, the semi-express service obtaining upon private right of way interurban line. When operating with frequent stops, such equipments run d. c. and have the same efficiency as standard d. c. equipments.

134. The **free running efficiency of a. c. equipments** may be taken at from 70 to 75 per cent. for equipments ranging in capacity from 50 to 200 hp. per motor, hence giving to the a. c. equipment an all round efficiency of about 70 per cent. whether accelerating or running at constant speed, a performance closely approximating that of the d. c. motor equipment.

135. The three-phase induction motor is installed upon but a few roads, and these are of the interurban types. Being practically a synchronous motor, there being but a maximum of ten per cent. difference in speed between full load and running free, it follows the law of the d. c. shunt motor at fractional speeds without having the advantage enjoyed by the latter of variable field intensity.

136. There are two **methods of control of induction motors** available for railway service, variable voltage in the primary and variable non-inductive resistance in the secondary. Variable voltage introduces an exceedingly poor power factor during the starting or fractional speed period, and also entails a prohibitive $I^2 R$ loss in the secondary, if this be of the short-circuited type. Voltage variation is only used in special cases where the excessive size of the motor required is no handicap.

137. The most operative method of control consists in providing the rotor with collector rings, inserting **non-inductive resistance** to absorb the e.m.f. until the increasing rotor speed develops sufficient counter e.m.f. to make it possible to short-circuit the collector rings at approximately ten per cent. below synchronous speed. As there is little or no motor-curve acceleration, the resistance method of starting results in a poor efficiency which may be partly offset by connecting **motors in tandem or concatenation**. As the speed of the induction motor is fixed by its frequency of supply and not by its impressed e.m.f. it is not possible to connect two such motors in series in the d.c. acceptance of the term. It is possible however, to connect the stator winding of motor No. 1 to the line, the rotor winding of motor No. 1 to the rotor winding of motor No. 2 and short-circuit the stator winding of motor No. 2 this constituting the concatenated method of connecting induction motors and corresponding in results to the series connection of d.c. series motors. With induction motors so connected, stability is obtained with half-speed of the rotors and a concatenated set can be treated in all respects as a single induction motor having double the number of poles in its field.

138. Concatenation is feasible only with motors of low frequency, 25 cycles or less, owing to the low power factor incidental to such a combination. In general, however, concatenation is used with railway induction motors, not to effect a possible increase in the efficiency of acceleration, but to provide a second efficient running speed for the low speed requirements in terminal yards.

139 Efficiency of Acceleration Three-Phase Induction Motors (see 140).

Per cent. straight line acceleration	100	90	80	70	60	50	40	30	20	10	0
Efficiency per cent.	40	43	46	49	52	55	58	61	64	72	75

140. The **accelerating efficiency** of an induction motor railway equipment is indicated in Table **139** for **parallel operation only,** concatenation not being considered. As straight line acceleration will constitute fully 50 per cent. of the total period during which power is supplied in a typical rapid transit run, an induction motor equipment will have an efficiency of acceleration not to exceed 55 per cent. This represents the power efficiency and does not include the power factor which will approximate 80 per cent. during acceleration with non-inductive resistance inserted in the secondary circuit, thus making the *apparent* efficiency of acceleration approximately 44 per cent.

Hence for acceleration problems involving a consideration of railway induction motors of the polyphase type, divide energy values given in Figs. 28 and 29 by .44 to get the volt-amperes input to the train at the train and *not including* any trolley or distribution losses.

141. In service calling for frequent starting and stopping of trains, it is evident that the $\frac{mS^2}{2}$, constituting the energy loss in heating brake shoes and wheels, forms a considerable percentage of the total energy input to the train. As the electric motor is reversible, that is, can absorb power and give out mechanical energy, or can give out electric power when mechanically driven as a generator, it seems feasible to expect that some means of control can be designed which will enable a train to be braked electrically with reduced wear and expense of brake shoes maintenance, besides **returning to the line** a considerable percentage of the **energy** delivered to the train during acceleration. Also on roads having excessive continous grades, it is desirable to return energy to the line partly for the economy thus effected, but largely to reduce the danger that goes with braking long heavy trains by means of brake shoes.

142. The standard d.c. motor, being of the series type, cannot be used directly as a d.c. generator, but some modification of shunt winding or separate excitation of the series field at low potential must be used in order to enable the **motor** to act **as generator when braking** the train. Of the total energy delivered to the train during a typical city run, nearly one-third of the amount is wasted due to the inefficiency of the motor, gears,

and method of control. Of the remaining two-thirds, fully 25 per cent is required to overcome train resistance, leaving 50 per cent of the original train input as available for regenerative purposes. Owing to the complications required to brake a series d.c. motor equipment available for generation, it would not be possible to effect the same efficiency of deceleration as the 70 to 75 per cent possible during acceleration. Furthermore, the capacity of a railway motor to do work is limited by its heating, and this heating is dependent upon the superficial area and weight of the motor, hence, if the motor is chosen with due regard for its safe temperature rise when used for accelerating the car, its thermal capacity must be increased in due proportion to the amount of extra motor **loss entailed in electrically braking** the car. This extra weight of equipment will in turn entail an additional expenditure of energy during accelerating period, so that the effect of brakng the train electrically with the same motive power used for acceleration, will be to considerably increase the duty of such motors, and hence, their weight and first cost.

143. Assuming that an **efficiency** of 60 per cent could be obtained **during retardation** by electric braking, it would mean the possible saving of 30 per cent in the energy consumption of the car, provided the car weight were not increased due to the larger motor capacity demanded. It is not possible, however, to effect any such economy as the figure indiccated, and from 15 to 20 per cent saving of gross input would more nearly represent the possibilities of regenerative control, on a class of service calling for very frequent stops. It is evident that where stops are infrequent as in high speed interurban service, the effect of regeneration would become negligible so far as economy of operation is concerned.

144. Considering the **question of regenerative control,** it is necessary to consider the first cost of the equipment and increased cost of maintenance as offsetting advantages derived from a possible smaller energy consumption of the car. It is not too much to expect that the car equipment will be increased fully 50 per cent in weight and first cost if regenerative control be adopted, and the possible 15 to 20 per cent energy must be balanced against the interest on the additional first cost and cost of maintaining the equipment.

145. As any system of regenerative control depends upon the counter e.m.f. of the revolving armature, it is evident that when approaching zero speed there will be no torque developed by the motor, and hence, **regenerative braking must be used in connection with air brakes,** with resultant decreased saving in economy.

For street car service, including interurban service, it can be said that there is small attraction in regenerative control, not because such control is not possible, but because the added complication and expense brings no adequate return in the cost of the energy saved.

146. Regenerative control used in connection **with locomotives** for heavy passenger or freight service **on mountain grade sections,** offers many advantages far outweighing in importance the possibility of a small amount of energy saved. One of the disadvantages attending the operation of long heavy trains on mountain grades is the danger incurred in breaking the trains on the down grades. More accidents occur when trains are running down grade than when operating up grade, due to the fact that overheated brake shoes and car wheels may cause a derailment, and also due to breaking apart of long trains when the brakes are released momentarily for the purpose of recharging the train pipe. On such classes of service, a regenerative system of control offers safer means of holding trains on down grades than exists with present air brake control, and its claims in this direction make it worthy of very careful consideration for this class of service.

The **three-phase induction motor** is a **perfectly reversible** motor without entailing the addition of the auxiliary apparatus required with d.c. series motor, and regeneration on down grades with the induction motor equipment is entirely practicable and constitutes one of the strong claims presented by this type of equipment for mountain grade service.

RAILWAY MOTOR CAPACITY.

147. The capacity of railway motors to do work cannot be measured by the same standards governing the **rating of motors** of the stationary

type. Conditions of operation demand that the motors shall conform to the requirements of a 4 ft. 8½ inch gauge track, and frequently a wheel base of not over 78 inches, and preferably less. The restricted space thus available makes it imperative that the weight and outside dimensions of railway motors shall be scaled to the lowest possible limit consistent with the average and momentary output demanded by service requirements. It is customary therefore, in railway motor design to force the density of the magnetic circuit far in excess of what is considered good practice in the design of stationary motors. The effect of this high saturation of the iron circuit is to entail an iron hysteretic and eddy current loss of such a high value as to preclude the possibility, in many cases, of running the motor continuously at full voltage without overheating it due to the iron loss alone. It is evident therefore, that recourse must be had to methods of comparative rating of railway motors other than the usual continuous running at full voltage obtaining in the case of stationary motors.

148. There are two factors which determine the **capacity of railway motors** to do work, namely: Commutation, and heating.

During the accelerating period the current input demanded by a railway motor is always considerably in excess of the current afterwards required to run the car at full speed on level tangent track. The value of this current will depend upon the several conditions entering into the problem, weight of train, schedule speed, and frequency of stops, these factors determining the rate of acceleration and maximum speed required as previously outlined. A motor must be selected which can commutate the abnormal current required during the accelerating period without excessive sparking at the brushes.

149. The commercial rating of a railway motor is the horsepower output it will deliver during a one hour run at rated potential at the brushes with a temperature rise of any part of the motor not exceeding 75 degrees C. above the surrounding air taken at 25 degrees C. Besides the commercial value of such a simple means of distinguishing motors of different capacity, the one hour rating has a further value of indicating approximately the maximum current which the motor should be called upon to commutate during the accelerating period. Thus, a motor having a commercial rating of 125 hp. with 208 amperes input at 500 volts, should be assigned to a class of work which will demand a current not much exceeding 208 amperes during the straight line portion of the accelerating or fractional speed-run period.

Example: Given a mile run made in 120 seconds, tractive effort 100 lb. per ton, including 15 lb. per ton train resistance, find maximum current input during acceleration for 100 ton train.

Answer: From Fig. 22, a gross tractive effort of 100 lb. per ton calls for maximum speed of 46.5 miles per hour in order to complete run in 120 seconds. Straight line acceleration is carried approximately 60 per cent. of maximum speed $= 46.5 \times .60 = 27.9$ mile per hour. The energy per ton-mile $= F_0 \times 2$, hence, $= 100 \times 2 = 200$ watt-hours per ton-mile. This output is delivered at a maximum speed of 27.9 miles per hour, hence, power input

$$\text{to the train} = \frac{200\text{x}100\text{x}27.9}{0.85} = 656 \text{ kilowatts (see } \mathbf{110}\text{).}$$

$$\text{Current} = \frac{656}{500} = 1312 \text{ amperes total for train.}$$

150. For close calculations it is necessary to plot the actual speed-time curves obtaining with any individual motor, but the above method of approximation is sufficiently accurate for a preliminary study. In dividing the total current input to the train by the number of motors, in order to get the current per motor it can be assumed that each motor will take its equal share of current at all speeds, provided the motors are of the same type and capacity, and have the same gear ratio.

151. It is evident from working out a few examples, that **high rates of acceleration** can be used only when low maximum speeds are possible and that it will call for an abnormally large motor capacity if high rates of acceleration are demanded in connection with high maximum speeds.

Thus, although motor equipments of the d.c. series type can always furnish enough current to slip the driving wheels, it will demand such high current inputs as will considerably exceed the safe rated commutating capacity of motors operating cars at the 50 miles per hour or more common to interurban high speed service. Various devices have been brought out for the purpose of limiting starting currents to safe predetermined values, and the current limiting device now forms a component part of certain types of control equipment.

152. The heating of railway motors in operation is caused by internal $I^2 R$, iron and brush losses. These losses vary not only in intensity but also in distribution with different types of motors and classes of service. At zero speed, the losses are all in the copper of field and armature, being divided according to their relative resistance, but as the armature speed increases there is an iron loss distributed, between the iron of armature and pole face and tips, depending upon the design of the motor. This iron loss starts from zero at standstill and increases to a maximum at the moment of cutting out starting resistances, after which it falls off somewhat, but this again is a matter of motor design. As these various losses are the cause of the motive power heating, it is necessary to trace their influence upon the individual parts of a motor under study.

153. As the heating of a motor is the result of the **average losses** within it, the average losses and their distribution up to any moment of shutting off power must be determined.

Internal motor losses during fractional speed running are indicated in Fig. 31, where abscissas give elapsed time and ordinates equal power lost. In other words, the losses depicted are not instantaneous losses at any given speed but integrated losses from the time of starting from rest to that speed.

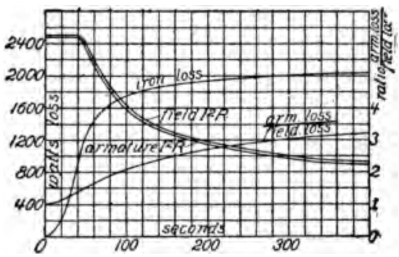


FIG. 31.—Starting losses.

154. Equally important with the determination of the various **internal losses** is their **distribution**, thus in a closed motor the armature loss must be conducted through the field structure before it can reach the outside surface of the motor and be dissipated into the surrounding air. Added to the heat imparted to the field structure by its own $I^2 R$ losses, there is therefore the considerable amount of heat delivered to it by virtue of its service as a conducting medium for the armature heat. On the other hand, the field structure would conduct the armature heat at a more rapid rate were it not for its own internal loss; hence it becomes important to establish a relation for this interchange of heat between field structure and armature, this relation being best expressed by the ratio of $\frac{\text{Armature loss}}{\text{Field loss}}$, as indicated in Fig. 31.

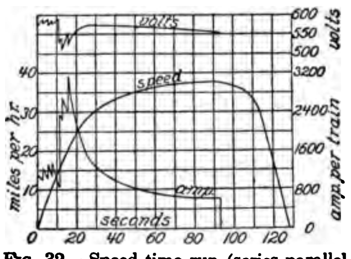


FIG. 32.—Speed-time run (series parallel control).

155. As **thermal capacity curves** furnish the foundation for all determinations of motor capacity for any service, it is important to understand the method of their construction. A typical speed-time run, Fig. 32, is performed over a tangent level track with proper weight of car and gear

ratio for a given motor, a succession of these runs being made fo ten hours, or until the motors have attained a constant temperatu typical run will call for certain internal losses in the motor havir ratio between armature and field losses, and there is a direct c between these losses averaged over the eight or ten hours run temperature rise of the several parts of the motor. Fig. 33 is structed from results of a series of such terperature runs, each ten-hour run giving rise to a certain ratio of armature to field lc therefore establishing one point upon the field and armature capacity curve.

156. Any given service operation although, made up of short runs, can be resolved into a **single typical speed-time curve** v call for the same internal losses and the same distribution of motor losses as would obtain under service conditions. By utilizing such data as given in the thermal capacity curve, Fig. 33, for a given motor, it is possible to predict, with reasonable accuracy, the temperature rise of a motor for any operating conditions coming within the limits of the motor capacity.

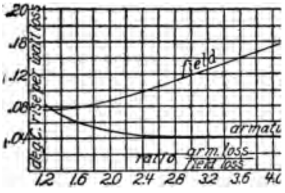


Fig. 33.—Thermal character

As such calculations demand a vast number of experimental runs, the expense of which can only be borne by railway mot facturers, some better form of expressing the relation of railw capacity and service performance is necessary for approximati Owing to the fact that railway motors of the d.c. series type hav standardized along certain lines, it is possible to establish a wo lation between the commercial one-hour rating of a motor and i to do work under service conditions.

157. Applying results similar to Fig. 33, to a series of speed-tir for different distances run, a curve similar to Fig. 34 is obtain equipment having a fixed gear ratio, in this case proportioned for a r speed of 45 miles per hour on tangent level track. This curve, "**service capacity curve,**" gives directly the temperature rise fc equipment, in this case a 125-hp. motor, for any schedule speed be performed with a varying number of stops per mile, the e being geared for 45 miles per hour maximum speed when running

158. It will be noted that the **tons train weight per motor for a given temperature rise** do not vary greatly over the whole range from five stops per mile down to less than one stop per mile. In other words, a railway motor equipment of fixed gear ratio when mounted on a car of fixed weight, will attain approximately the same temperature rise above the surrounding air, irrespective of the number of stops per mile demanded by service conditions. Thus from Fig. 34, 16 tons per motor temperature rise of 60 degrees C for the motor under considera this temperature rise holds good whether the car is making a schec of 11.5 miles per hour with five stops per mile, or 29 miles per h one stop per mile.

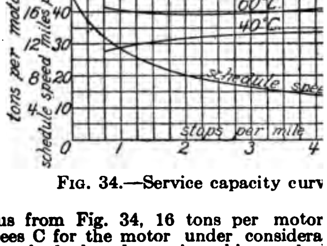


Fig. 34.—Service capacity curv

This fact furnishes a means of simplifying the expression

relation between the one-hour commercial capacity test and service capacity of the railway motor. It is sufficient for purposes of approximation to rate a given motor at the tons train weight per motor which can be hauled for a given maximum speed or gear ratio, taking say 60 degrees C rise as a basis.

159. Owing to the fact that preliminary calculations do not start with any given motor as a basis, it becomes preferable to express the values given in curves similar to Fig. 34 in a more convenient form. Such values are given in the following tables expressing the **relation between the maximum train speed** when running free on tangent level track **and the horsepower commercial rating** of railway motors required to limit the temperatures rise to 60 degrees C above the surrounding air taken at 25 degrees C. A temperature rise of 60 degrees C has been taken in order to ensure a reasonably long life to the motor insulation, a much higher temperature rise causing a too rapid deterioration.

160. Horsepower Motor Capacity Required (161). Standard 500 Volt D.C. Motors (see 161.)

SINGLE-CAR UNITS.

Max. speed miles per hr.	Hp. required for gross weight of equipped car including passengers, of				
	20 tons	30 tons	40 tons	50 tons	60 tons
30	120	155	190	225	255
35	145	190	240	280	315
40	180	230	295	345	390
45	215	275	350	405	455
50	—	320	410	475	525
55	—	—	465	545	600
60	—	—	525	620	690
65	—	—	—	710	790

TWO-CAR TRAINS

Max. speed miles per hr.	2-20 tons	2-30 tons	2-40 tons	2-50 tons	2-60 tons
30	190	255	315	375	440
35	235	310	390	470	545
40	285	375	480	570	665
45	335	445	560	670	775
50	—	520	655	785	900
55	—	—	750	900	1030
60	—	—	850	1010	1160
65	—	—	—	1140	1320

THREE-CAR TRAINS

Max. speed miles per hr.	3-20 tons	3-30 tons	3-40 tons	3-50 tons	3-60 tons
30	255	350	435	530	625
35	310	430	540	660	770
40	370	520	650	800	920
45	440	610	770	930	1080
50	510	700	900	1080	1260
55	—	800	1030	1240	1430
60	—	—	1160	1430	1620
65	—	—	1310	1600	1830

FIVE-CAR TRAINS

Max. speed. miles per hr.	5-20 tons	5-30 tons	5-40 tons	5-50 tons	5-60 tons
30	375	510	680	840	970
35	460	640	830	1030	1230
40	560	770	1010	1230	1470
45	670	900	1180	1450	1710
50	770	1070	1370	1680	2010
55	—	1240	1570	1920	2300
60	—	—	1770	2190	2580
65	—	—	2010	2480	2910

161. These **tables of motor capacity** (160) are based upon the temperature rise of 60 degrees C above surrounding air, assumed to be 25 degrees C. The horsepower capacity required conforms to the commercial rating of railway motors, that is, the one-hour hp. rating which will occasion a temperature rise of 75 degrees C. above surrounding air, taken at 25 degrees C.

162. The **horse power capacity** given for any train weight may be **split up into** the required number of **units.** Thus, a train composed of five forty-ton cars running at forty-five miles per hr. requires 1180 hp. motor capacity. This may be divided into six units of 200 hp. each, that is, three motor cars equipped with double 200 hp. motors hauling two trailers, or each car of the train may be a motor car and be equipped with a pair of 120 hp. motors. Approximately the same temperature rise will obtain in either case.

163. For **single-car operation** a four-motor equipment is preferred for double truck cars, this being especially true where snow or heavy grades are characteristic of the service. For **train operation,** two-motor equipments are used, as the disabling of a single unit will not incapacitate the train.

The horsepower capacity specified above for train operation should be made use of only when cars are always operated in trains and never singly. For example, five forty-ton cars operating in a train at 60 miles per hr. require a motor capacity of 1770 hp. or 354 hp. per car, a motor capacity too low for single car operation which demands 525 hp. Hence, where cars are run indiscriminately, singly and in trains, the full motor capacity per car should be taken as given in the table of single car operation.

164. The **motor capacities given in Table (160) are approximate** only and are intended as a guide in preliminary calculations. Where accuracy is demanded, or where operating conditions are abnormal, it is necessary to plot speed-time-distance curves for the particular motor characteristics and conditions obtaining, from which the motor temperature should be calculated from a detail knowledge of the motor thermal constants. The method is indicated previously in this description.

165. Owing to the short period during which **single-phase** motors have been operated, their design has not yet become standardized, nor is there sufficient operating data upon which to base anything more than general conclusions of the **horsepower required for a given service.** The single-phase motor is essentially a high speed motor, having a high copper loss and low core loss, hence being more particularly adapted to constant speed running, and suffers in comparison with the d.c. series motor when used for acceleration work. There is no lack of starting torque with the a.c. motor, but a large tractive effort is obtained only at the expense of a large copper loss, so that a.c. motors are unsuitable for rapid transit service demanding repeated high rate of acceleration, not because such motors cannot furnish the tractive effort required, but because the copper loss incident to such high tractive efforts will heat the motors unduly if used exclusively for acceleration service. Thus the a.c. motor becomes much heavier than the d.c. motor on the basis of service performed with frequent stops.

166. In **interurban or express service** with infrequent stops, the smaller core loss of the a.c. motor brings it more nearly on a par with the d.c. series motor as regards output per pound weight of motor. It is possible therefore to use Table **160** as applying to a.c. motor capacity where stops are not greater than one in two miles, but the table should not be used in connection with higher frequency of stops given, as then the resulting motor capacity indicated in the table must be largely increased when applied to a.c. motors.

167. Owing to the fact that the **chief advantage of the single-phase motor** lies in its ability to utilize the benefits of a trolley potential considerably in excess of the standard 600 volts used with d.c. motors, questions of safety limit the field of operation of a.c. motors to interurban lines operating over private right of way, a class of service where stops are infrequent. Hence, the a.c. motor should not be considered for any project calling for a frequency of stops much greater than one in two miles, partly on account of the excessive motor capacity required, and also due to the fact

that such frequent stop service can be considered from the d.c. motor standpoint with almost equal economy in the first cost of the complete system.

168. Owing to the few applications of three-phase induction motors to railway conditions, no statements can be made regarding the capacity of such motors for service performed. The induction type of a.c. motor is not at all adapted for acceleration work, owing to the poor efficiency of the car equipment during fractional speed running. The **field of the three-phase induction motor** lies in the direction of a service calling for constant effort at constant speed, and the problems wherein this type of motive power can be considered are so special and infrequent as to place it entirely outside the lines of standard apparatus.

169. Locomotive operation demands a special treatment of the motor capacity subject, in most cases requiring such special knowledge of the motor construction as to prevent any general conclusions being drawn with the limited data at hand. The **locomotive motor is designed** more along the lines of a stationary motor, that is, owing to the necessity of operating a locomotive close to the tractive limit, its motive power is running continuously at nearly its full load. With a locomotive working at 75 per cent or more of the slipping point of the drivers, there is a possibility of but small overload and hence the motors may be designed with lower density, in fact like a stationary motor. With the absence of extreme overloads, the question of commutation becomes secondary and the selection of a motor becomes a matter of its ability to radiate the heat generated for the service specified. The whole question of motor capacity for locomotives is so intimately connected with mechanical problems of locomotive design, that it must be placed in the list of special problems requiring the careful co-operation of the manufacturers.

170. Forced ventilation is being resorted to especially in the case of the larger motors for locomotives, as owing to the limits imposed by standard gauge and allowable wheel base it often becomes extremely difficult to concentrate the required motor power without exceeding safe temperature limits. As the size of locomotive motors is largely determined by their ability to radiate heat, the use of forced ventilation naturally follows as the next step in advance.

171. Standard G.E. Railway Equipment (see 172).

D.C. Type

Trade Name	hp.	No. of Motors	Type of Control	Weight of Control	Weight of motor including gear and gear case	Total weight of Equipment
GE-800	25	2	K-10	940	1930	4800
		4	K-12	1175		8895
GE-54	25	2	K-10	940	1831	4602
		4	K-12	1175		8499
GE-60	25	2	K-10	940	1665	4270
		4	K-12	1175		7835
GE-1000	35	2	K-10	940	2200	5340
		4	K-28	1350		10150
GE-78	35	2	K-10	940	2560	6060
		4	K-28	1350		11590
GE-58	35	2	K-10	940	2150	5240
		4	K-28	1350		9950
GE-67	40	2	K-10	940	2385	5710
		4	K-28	1350		10890
GE-70	40	2	K-10	940	2745	6430
		4	K-28	1350		12330
GE-80	40	2	K-10	940	2800	6540
		4	K-28	1350		12550
GE-53	45	2	K-11	1015	2755	6525
		4	K-14	2250		13270
GE-57	50	2	K-11	1015	2972	6954
		4	K-14	2250		14138
		4	Mult. Unit	2671		14559

171. (*Concluded.*)

Trade name	hp.	No. of motors	Type of control	Weight of control	Weight of motor including gear and gear case	Total weigl of equipmen
GE-90	50	2	K-11	1015	2875	6765
		4	K-14	2250		13750
		4	Mult. Unit	2671		14171
GE-87	60	2	Mult. Unit	1765	3510	8785
		4	Mult. Unit	2671		16711
GE-74	65	2	Mult. Unit	1922	3534	8990
		4	Mult. Unit	3052		17188
GE-73	75	2	Mult. Unit	1922	4022	9966
		4	Mult. Unit	3158		19246
GE-66	125	2	Mult. Unit	2715	4375	11465
		4	Mult. Unit	3749		21249
GE-55	160	2	Mult. Unit	3141	5415	13971
		4	Mult. Unit	5385		27045
GE-76	160	2	Mult. Unit	3141	5152	13445
		4	Mult. Unit	5385		25993
GE-69	200	2	Mult. Unit	3379	6230	15839
		4	Mult. Unit	5768		30688

172. In the list of standard motors (**171**) there is included a numb of motors that are superseded by later types, but owing to their widesprea use, data concerning them are included for comparison. For motors of 5 hp. and above, the multiple-unit system of control is preferable, whil for smaller motors the use of hand or multiple-control is optional dependin upon local requirements.

173. Standard Westinghouse Railway Motors.

Trade name	hp.	No. of motors	Type of control	Weight of control	Weight of motor including gear and gear case	Total weigh of equipment
12-A	25	2	K-10	940	2200	5500
	25	4	K-12	1175		10250
69	30	2	K-10	940	1950	4900
	30	4	K-12	1175		9100
49	35	2	K-10	940	1925	4900
	35	4	K-28	1350		9300
92-A	35	2	K-10	940	2265	5600
	35	4	K-28	1350		10700
38-B	40	2	K-10	940	2250	5950
	40	4	K-28	1350		12150
68-C	40	2	K-10	940	2280	5700
	40	4	K-28	1350		10700
101	40	2	K-10	940	2645	6430
	40	4	K-28	1350		12160
101-C	40	2	K-10	940	2730	6600
	40	4	K-28	1350		12500
39	50	2	K-11	1015	2900	7000
	50	4	K-14	2250		14200
93-A	50	2	K-11	1015	3355	7910
	50	4	K-14	2250		16020
56	55	2	K-11	1015	3000	7200
	55	4	K-14	2250		14600
112	65	2	Unit switch	1125	3400	7925
	65	4	Unit switch	2400		16000
76	75	2	Unit switch	1770	3840	9450
	75	4	Unit switch	3640		19000
85	75	2	Unit switch	1770	4500	10780
	75	4	Unit switch	3640		21640
121	85	2	Unit switch	1770	4300	10370
	85	4	Unit switch	3640		19400
119	125	2	Unit switch	1770	4600	10900
	125	4	Unit switch	3640		21880
113	200	2	Unit switch		6700	19100
	200	4	Unit switch			

RAILWAY MOTOR CONTROL.

174. There are two general types of **control used with d.c. series railway motors,** namely: Hand control, and multiple unit control.

The distinctive feature of **hand control** is that the various electrical contacts are made and broken manually, the working parts being encased in a controller located in the vestibule of the car. The hand controller consists of an upright cylinder divided into contact segments which bear in succession against stationary fingers and thus accomplish the necessary electric connections.

175. Hand controllers are divided into the following types:

Type "K" controllers are of the series-parallel type and include the feature of shunting and short-circuiting one of the motors when changing from series to parallel connection.

176. Type "L" controllers are also of the series-parallel type, but completely open the power circuit in changing from series to parallel. Type "L" controllers are used for motors of 50 hp. and above, and are largely superseded by multiple-unit control.

177. Type "R" controllers are of the rheostatic type, and are designed to control one or more motors by means of resistance only. They make no provision for series-parallel connection and are therefore limited in their field of application.

178. Type "B" controllers may be either of the series-parallel or rheostatic type, but they always include the necessary contacts and connections for operating electric brakes.

179. The rated capacity of controllers is based upon the maximum horsepower of motors with which they can be used, the motors being rated in accordance with standard practice, that is, the output which can be obtained for one hour with a rise in temperature of the motor not exceeding 75 degrees C. All controller ratings are based upon a nominal potential of 500 volts. If controllers are to be used on lower voltages the horsepower ratings will be proportionately less. While nominally designed for 500 volts, controllers may be used successfully at maximum potential not exceeding 600 volts.

180. Standard Series-Parallel Controllers*

Title	Capacity	Controlling points
K-10	2-40 hp. Motors	5 Series 4 Parallel
K-11	2-60 hp. Motors	5 Series 4 Parallel
K-12	4-30 hp. Motors	5 Series 4 Parallel
K-28	4-40 hp. Motors	6 Series 5 Parallel
K-14	4-60 hp. Motors	7 Series 6 Parallel

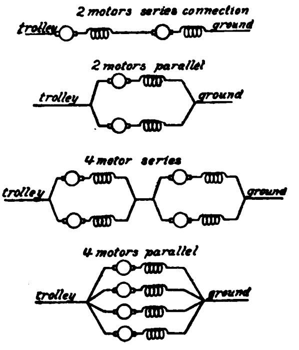


FIG. 35.—Diagram control.

181. The **object of a series-parallel controller** is to effect series connection of motors with full starting resistance in circuit, cut out starting resistance in successive steps until full line potential is across two motors in series, change from series to parallel connection of the motors with full starting resistance in circuit, cut out starting resistance in successive steps until motors finally operate in parallel with full line potential across their terminals, each motor being subjected to full line potential.

182. In order to **increase** the **reliability and efficiency of** the present **drum type controllers** when opening the main circuit on heavy overloads due to damaged motors or other causes, there has been developed a com-

* *For* **motors above 60 hp.,** multiple-unit control is preferred.

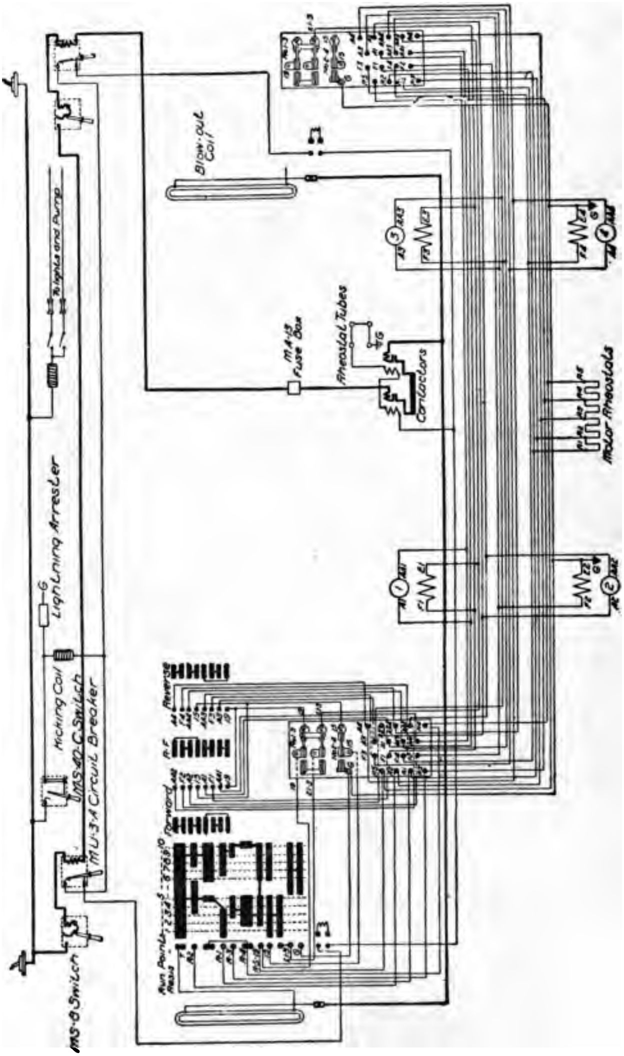


Fig. 36.—Diagram K-28-F controller.

bination system of control, using standard electromagnetic contactors to open the circuit under the car

The first controller to be fitted with this system was the K-28 which is rated at four 40-hp. 500 volt motors. With the use of contactors, resulting in the elimination of arcing in the controller on opening the main circuit, the wear of contacts is greatly reduced. It has thus been possible to increase the rating of the controller to four 50-hp. 500 volt motors, the limiting feature being the current carrying capacity of the different parts. As the contactors are placed in the main circuit between the controller and trolley, they prevent an arc from holding between the trolley finger and any grounded portion of the controller after the controller has been turned to its off position.

183. The **controller** when **fitted for operation with contactors** is known as the K-28F- or J. This controller is provided with an auxiliary contact device situated at the base of the main cylinder. It consists of two contact fingers which are operated by a pivoted arm and a projection on the fibre disc at the bottom of the cylinder. The fingers are normally held open at the off position by the projection. On turning the controller cylinder, the main operating fingers make contact and then the projection on the disc disengages, allowing the auxiliary fingers to close.

184. A magnetic blowout is provided in the device to extinguish the arc when the fingers open to the off position. One of these fingers is connected to the operating coils of two standard contactors operating in series, the other through a switch and fuse to trolley. The main circuit after passing through a protective device, such as switch and fuse or circuit-breaker, connects to the contactors, then to the controller and thus to motors.

185. A projection is also provided on the disc to open the contactors in passing from series to parallel. It will readily be seen that with this arrangement all heavy arcing occurs in the contactors and not in the controller.

The two contactors, with resistance tubes which are placed in series with the operating coils, are mounted in a sheet iron box located under the car.

186. A further development of this system is in using the contactors as circuit-breakers. This is accomplished by the use of an auxiliary circuit-breaker, known as the MU-3, the tripping coil of which is in the trolley circuit, and the contacts in the circuit feeding the contactor coils. This auxiliary circuit-breaker can be set to trip at any predetermined current between certain limits. When the current reaches the predetermined point, the tripping coil pulls in the armature and opens the switch, thus breaking the contactor operating circuit and opening the contactors. The switch can also be tripped by throwing the handle to the off position.

The auxiliary contact device is also manufactured for use with K-6, K-10, K-11, K-12 and K-14 controllers and can be readily attached to any of these controllers.

187. The **multiple-unit** type of control was brought out primarily for the control of motor cars in a service requiring that cars be operated singly or several coupled together in a train and operated simultaneously. When several cars are coupled together in a train, the train connections are so arranged that the motors on all of the motor cars may be controlled from either end of any motor car by a single operator, the cars being coupled in any desired relation and with either end of any car connected to any other car in the train. Although designed for train operation the multiple-unit type of control is used almost universally for the control of single-car equipments where the motors have a capacity of 50 hp. or greater, owing to excessive size and weight of hand type of control used with motors of large capacity

188. Train-control systems consist in general of two parts, the first consisting of a series-parallel motor controller composed of a number of switches or circuit-breakers, sometimes called contactors, whose function is to effect the different electrical combinations of the motors and regulate the starting resistance in circuit with them. There is also a reverse switch for the motors called a reverser, which is actuated by the same means used to operate the circuit-breakers or contactors. The second part comprises master controllers which operate the motor controlling contactors and reversers through the medium of train wires extending throughout the length

of train so operated. A single operator is able to simultaneously effect similar combinations upon the several motor cars composing the train thus giving to the train the same advantages of large tractive effort and rapid acceleration obtaining in single-car operation.

189. The two systems of multiple-unit train control in operation differ in the means employed to actuate the contactors and reversers, the General Electric contactor being operated electrically by the line current, while in the Westinghouse train control system the contactor is closed and opened by compressed air, the necessary valves being actuated electrically by the master controller through a train cable using storage battery current. Each system aims to produce the same result, that is, duplicate the performance of a car operated singly, but they differ in the means adopted to secure this end.

190. There are two general **types of multiple-unit control marketed by the General Electric Company**, namely: The multiple-unit control proper, and the multiple-unit control used in connection with automatic acceleration as effected by current limiting relays and interlocking switches on the contactors.

191. The multiple-unit system of control with **manual controlled acceleration** is in general use both for train and single car operation. It is in effect the same as the hand-operated cylinder type of control except that instead of combining all the various circuit-breaking contacts upon a single cylinder operated by hand, it divides each contact into a separate circuit-breaker or contactor, and actuates these electrically through train wires by means of a small master controller.

The motor-control therefore, comprises those parts which handle motor current, all of these parts being electrically operated and located underneath the car.

192. The **master control** comprises those parts which handle the control current for operating the motor-control apparatus, the master controller being operated by hand and located in the vestibule at either end of the car. The motor-control is local to each car and current for this circuit is taken directly from the trolley or third rail through the circuit-breakers or contactors, starting resistance and reverser to the motors and thence to the ground. Where it is necessary to operate with a gap in a third rail system it is sometimes customary to install a train line so that any car may supply the motor current for the other cars in the train.

193. The master control consists of train wires made continuous throughout the train by means of couplers between cars. On each car the operating coils of the motor-control are connected to this train line through a cutout switch, these train wires being energized in proper sequence by the hand operated master controller on the platform. **Current for the master control** is taken directly from the trolley or third rail, through whichever master controller is being operated by the motorman, to the train line and thus to the operating coils of the contactors forming the motor-control on all cars in the train.

194. The master controller is similar in design to the original cylinder controller in that it contains a movable cylinder and stationary contact fingers are used to supply current in proper sequence to the different wires of the train line for energizing the operating coils of the motor-control. The value of current required is very small, not exceeding 2.5 amperes for each car in the train. The master controller is provided with two handles, one for operating and one for reversing the direction of the train movement.

195. The operating handle is provided with a button which must be kept down except when the handle of the controller is in the off position, as releasing this button permits an auxiliary circuit to open, cutting off the supply of current in the master controller and thus de-energizing the train line and opening up the motor-control apparatus. This button is intended to serve as a safety appliance in case of physical failure of the motorman.

196. The reverser handle is connected to a separate cylinder which establishes control connections for throwing the electrically operated reverser either forward or reverse position when the master-controller handle is on the first or off point. The operating circuit for the reverser is so interlocked that unless the reverser itself corresponds to the direction of the movement indicated by the reverser handle of the master controller, the line contactors on that car cannot be energized.

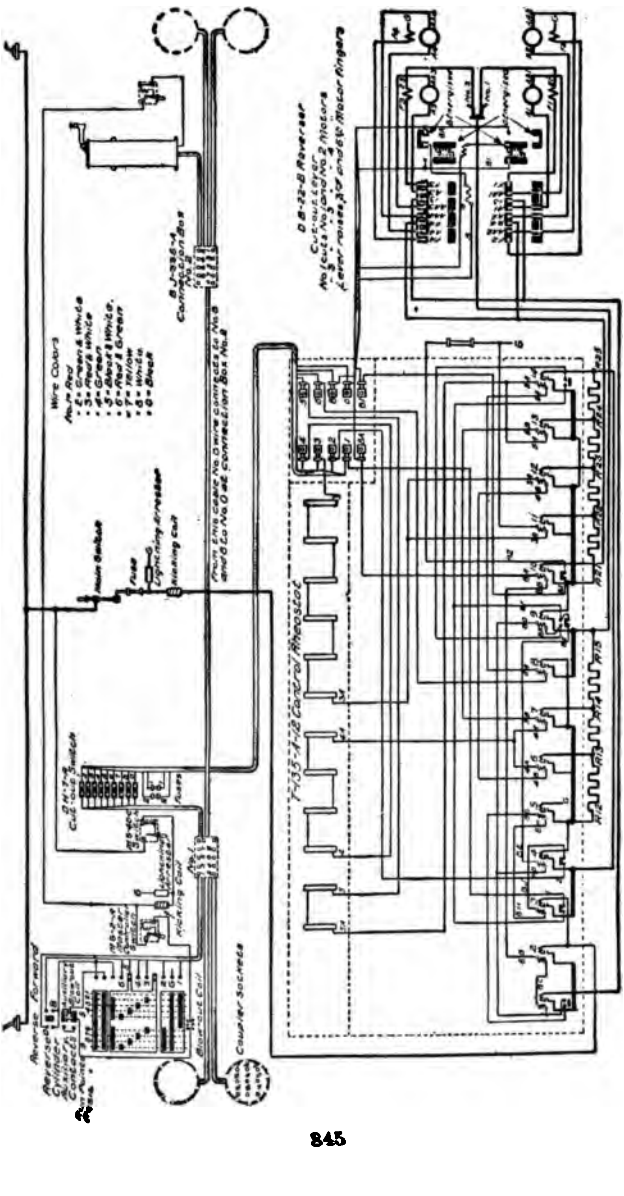


FIG. 37.—Diagram S. G. E. multiple-unit control.

197. The contactor is a switch operated by solenoid coils, and each contactor may be considered as the equivalent of a finger and its corresponding cylinder segment in the hand-operated "K" type controller. It consists of an iron magnet frame with an operating coil and two main contacts, one fixed and the other directly connected to the movable finger. These main contacts open and close in a moulded insulation arc chute provided with a powerful magnetic blowout. Interlocks are provided for making the necessary connections in control circuits to ensure proper sequence in operating the different contactors.

All of the contactors are mounted in a box placed on a wooden insulating support beneath the car, this box being provided with a sheet iron cover lined with insulating material.

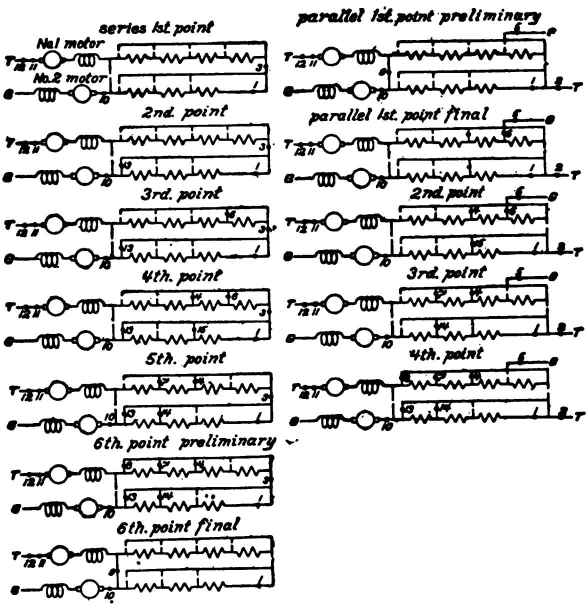


FIG. 38.—General scheme S. G. E. automatic control.

198. The reverser is a switch, the movable part of which is a rocker arm operated by two electromagnets working in opposition. The coils receive their energy from the master controller through the train line, and the connections are such that only one coil can be operated at a time. Leads from the motors are connected to the main reverser fingers and by means of copper bars on the rocker arm, the proper relations of armature and field windings are established for obtaining forward or backward motion of the car.

199. Couplers between cars are so designed as to give a corresponding connection of train wires, this being secured by means of proper mechanical design of plug and sockets as shown, it being impossible to improperly insert the plug in the sockets.

In changing from series to parallel connection of the motors with the "K"-controller, one motor is shunted during the operation, but with the train control the so-called "bridge" method of connection is used.

By this connection the circuit through the motors is not opened during the transition from series to parallel and substantially the torque of both motors is preserved at all times from the series to the full parallel connection.

200. Sprague General Electric automatic multiple-unit control provides for the **acceleration** of the train at a **predetermined** current in the motor, this feature being provided without preventing the manual operation of the master controller at less than the predetermined current if desired.

The operation of the contactors is controlled from the master controller, but governed by a notching or current limit relay in the motor circuit, so that the accelerating current of the motors is substantially constant.

This is accomplished by having small auxiliary interlocking switches on certain of the contactors, the movement of each connecting the operating coil of the succeeding contactor to the control circuit. The contactors are energized under all conditions in a definite succession, starting with the motors in series with all resistance in circuit; the resistance cut out step by step; the motors then connected in parallel with all resistance in, and the resistance again cut out step by step. The progression can be arrested at any point, however, by the master controller and is never beyond the point indicated thereby. The rate of the progression is governed by the **current limit relay** so that the advance is not made faster than will keep the current in the motors within the prescribed limit.

201. One of these relays is provided with each car equipment so that while the contactors on each car of a train are controlled from the master controller in use for the application and removal of power, the rate of progression through the successive steps is limited by the relay on each car independently, according to the adjustment and current requirements of that particular car.

202. Another automatic protection for individual cars is provided by a second or **potential relay** having its coil connected to the lead from the collecting shoes of the respective car and its contacts so connected in the contactor circuits that in case of failure of power to any car, such as would be caused by passing over a dead section of rail, this relay is de-energized and causes the control circuits on that car to be thrown back to series position with resistance in, and when power is restored the control progresses step by step to its former advanced position. This prevents any surging or overloading in such contingencies.

203. There are five **circuits leading from the master controller** and five corresponding train wires. The five circuits comprise one for forward direction, one for reverse, one each for series and parallel, and the fifth for controlling the acceleration.

204. When the master controller is moved to its **first forward point**, the No. 4 direction wire is energized which throws the reverser to its forward position, if it is not already so thrown.

The **reverser** is electrically **interlocked** so that it cannot be thrown when the motors are taking current.

The operating current is so arranged that unless the reverser is thrown for the direction of car movement indicated by the master-controller handle, the contactors and motors on that particular car are inoperative.

When the reverser has moved to the proper position, connections are made by it from the direction wire through the forward reverser operating coil and the coils of the contactors which control the main or trolley leads to the motors.

205. At the same time the series-contactor is energized by means of a second train wire and the circuit through the motors in series is completed with all resistance in circuit, giving a slow speed forward. In this position no further action is produced. When the master controller is moved to its **second forward position,** circuit is completed through the accelerating wire (No. 1), in addition to the above circuits which energizes the contactor shunting the first resistance step, and current also passes through the fine wire coil and the contacts of the current limit relay.

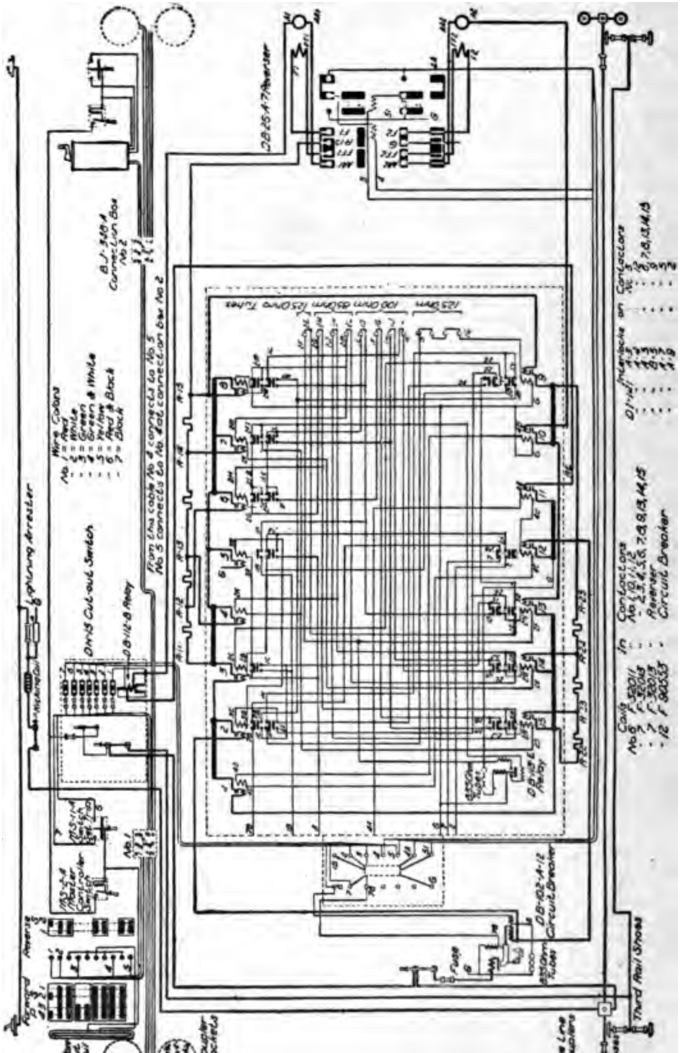


FIG. 39.—S. G. E. automatic-relay control diagram.

206. The plunger in this relay has a lost motion, so that an appreciable time is required to move it, and this time is made the same as that required by the contactor in closing its contact. These two devices thus operate simultaneously. The contactor being lifted, shifts its operating coil by means of the interlocking switches into the circuit through the series contactor above mentioned, which maintains it in the closed position independent of the circuit that has lifted it. At the same time the relay has opened the lifting or actuating circuit.

207. The shunting of the resistance step by the contactor causes an increased current to flow through the motor circuit and through the heavy coil of the relay, which is sufficient to hold the relay plunger in its raised position and so keep the actuating circuit open until the motors, by speeding up, cause the current to diminish enough to allow the relay plunger to drop and again close the accelerating circuit. Circuit is now established through the contactors shunting the second resistance step, and these contactors are energized and the relay again lifted and held up by the increased current and so on until all the resistance is cut out.

208. When the master controller is moved to the **third position** the parallel circuit is established, the bridge-contactor and then the parallel contactors closed and the motors connected in the multiple arrangement. When the master controller is moved to its fourth or **full-on position,** the resistance is cut out step by step as in series.

209. These same successive actions are produced if the master controller is thrown to the **full-on position directly,** as the interlocking contacts prevent an advance circuit being established before the proper preliminary action has taken place.

210. If at any point during the acceleration, the master controller is moved to its lap position, the existing position of the contactors is maintained, but the further progression is arrested so that the motorman can limit the acceleration to as slow a rate as desired, but he cannot exceed the predetermined rate for which the relay is adjusted.

211. A **control cut-out switch** is provided in each car so that in an emergency the operating coils of the contactors, reverser and circuit-breaker on a particular car may be disconnected from the control circuit.

It is necessary to positively energize two distinct train wires in order to operate the contactors required for starting the motors.

Three separate contactors with their main contacts in series are used for completing and breaking each motor unit.

Several small **fuses** are provided in the control circuit for effectively protecting the control apparatus.

Should the train break in two, the control current is automatically and instantly cut off from the detached rear portion without effecting the ability of the motorman to control the front part of the train.

212. The **Westinghouse multiple-unit control** is similar in many respects to the train-control system brought out by the General Electric Company, but differs in the means used to actuate the separate switches or contactors. While the General Electric Company electrically operate the switches energized from the trolley or third rail, the unit switches of the Westinghouse control are actuated by means of compressed air obtained from the air-brake reservoirs and the needle valves controlling the admission of air to the switches are in turn actuated by means of storage-battery current controlled through train wires and master controller. The two systems are therefore, similar in principle as regards the master controller, train line and contactors, but differ in the source of power used to energize the train wires and actuate the contactors.

213. The Westinghouse multiple-unit system of control is divided into two parts, the first or **motor-control system** consisting of a group of unit switches, a reverser switch and a set of starting resistances by means of which the various motor and starting resistance combinations are effected.

The second part or **auxiliary control system** comprises a set of train wires, a storage battery, electrically operated valves operating the pneumatic unit switch, a master controller and auxiliary protecting devices. The scheme of operation consists of the following progression:

214. The **master controller** is normally **in** the **central position** and completes a circuit which energizes the emergency train-brake magnet valve, releasing the air from train pipe and setting the brakes. Whenever

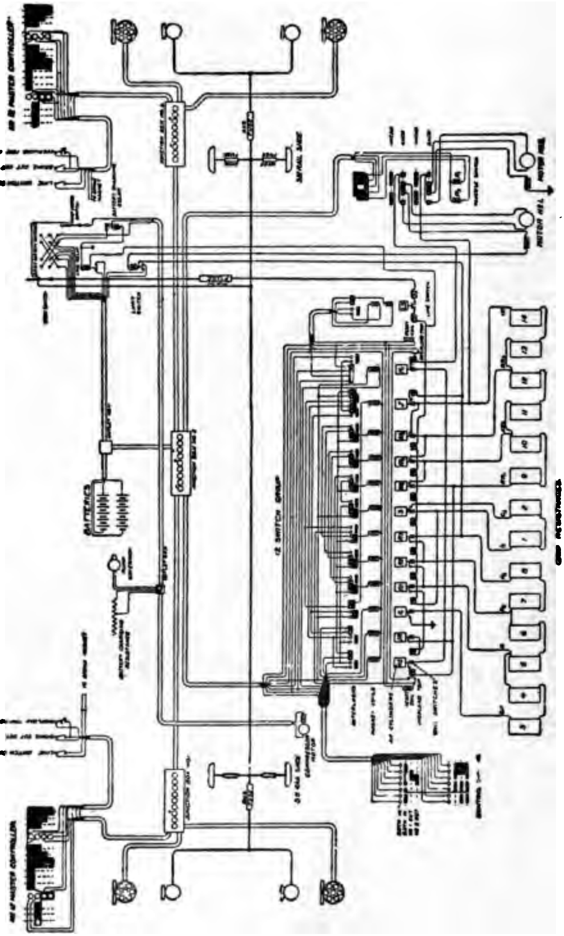


Fig. 40.—Westinghouse multiple-unit control.

the master-controller handle is returned to the central position, which it does automatically if the operator's hand be removed, it opencircuits the *current supply* and sets the brakes, bringing the train to rest; hence, consti-

tuting a safety device to take care of possible physical failure of the motorman.

215. The **first notch** is a coasting position of the controller, as this position opens all motor switches but does not apply the air brakes.

The **second notch** or switching position establishes connection with the train line so that the reversing switch is thrown to the proper position, the main line switch closes and the unit-switch group closes the circuit of the motors in series with all resistance in.

The **third notch** or full series position of the master controller handle introduces the current limit relay which permits the progressive picking up of the several unit switches as the current falls below a predetermined value. With the controller handle upon the third notch no further progression is made after the current relay has permitted the closing of the proper unit switches to effect full series connection of the motors with starting resistance entirely cut out.

The **fourth notch** on the master controller corresponds to multiple connection and advancing to this point establishes multiple connection of the motors and again brings the current relay into activity, permitting the progressive cutting out of multiple-starting resistance until full multiple operation with full line voltage upon the motors is attained.

Moving the master controller handle to similar notches upon the opposite side of the center notch will effect the same combinations, but with the train operating in the reverse direction.

216. The **office of the master controller** is simply to conduct the storage-battery current through the proper train wires to the electrically operated valves actuating the pneumatic unit switches. No current other than the battery current is in the master-controller circuit; hence, these parts are insulated only for 14 volts.

Should the line switch be opened or should the current be cut off from the line for any reason, the plunger of the line relay magnet drops, the battery circuit is opened, and all the unit switches are opened. This arrangement prevents the motors being held across the line subject to damage should the line current be suddenly resumed after the train has lost its speed.

217. **The master controller** has nine **notches,** the center notch being the off or braking position, opening all unit switches and applying the air brakes. No. 1 notch is coasting position; No. 2 notch series connection or motors with resistance in; No. 3 notch full series, and No. 4 notch full multiple; these figures applying to the four notches on either side of the central position, they being similar in the combinations effected, except that the motion of the car is reversed for similar positions on either side of the central notch. Owing to the low voltage of the battery current and the small number of points required, the master controller is very small and compact.

218. **The unit switches** are placed in a group, being assembled on a common frame and placed in a box beneath the car. The unit switch consists of a powerful circuit-breaker having a fixed and movable contact and provided with a magnetic blowout, the movable finger being actuated by an air cylinder energized from the brake reservoir and controlled by a magnet valve connected electrically to the train wire system. The switch finger is normally held open by a powerful spring which is compressed on closing the switch by reason of the greater power of the compressed air at 70 pounds pressure or more. The high pressure used inclosing the switch is also made use of to reduce the resistance, hence reducing the heating and size of the switch contacts.

219. **The reverse switch** consists of an insulated block carrying two sets of metal strips arranged to make contact with stationary fingers when operated forward and backward by a pair of pneumatically operated pistons actuated through electrically operated valves by the auxiliary or master controller. No magnetic blowout is required as the reverser does not operate when carrying current. This switch is enclosed in a sheet iron box placed beneath the car floor.

220. **The series limiting switch** regulates the feeding of the controller. It consists of a magnet coil in which operates a plunger terminating in a disc

which makes contact with the storage-battery circuit whenever the current falls below a predetermined amount. This switch used in connection with interlock switches, forming part of the auxiliary control system, permits the progressive cutting out of starting resistance.

221. Interlock switches consist of spring-contact fingers sliding on segments electrically connected to the magnet valve in such a manner that the closing of one energizes the valve magnet of the switch next succeeding, thus producing an automatic progressive action providing for uniform acceleration with practically constant motor current.

222. The **line relay** consists of a coil connected across between the main motor-control circuit and the ground. When the line switch closes and there is current on the motors, the coil of the line relay is energized, lifts the plunger and causes the disc to close the circuit between the contacts. These contacts are directly in series with the battery circuit of the switch group, and hence, if the motor current fails for any cause, this auxiliary contact is opened, thus opening the battery circuit to the unit switches and throwing the control to the off position. This line relay constitutes a safety device that will prevent re-establishing of the current after the motors have lost their speed.

223. The motor cut-out switch does not open the motor circuit direct, but consists of a hand-operated segmental drum engaging a number of contact fingers which are directly connected with the auxiliary control system. When this control-circuit switch is in the off position none of the fingers makes contact, making the control equipment inoperative. There are three other positions, two both in, three No. 1 out, four No. 2 out for a two-motor equipment, and the desired motor connections are effected with the cut-out switch handle in the corresponding position.

ALTERNATING-CURRENT MOTOR-CONTROL.

224. The single-phase motor is essentially the same in its characteristics as the d.c. series-motor, and can be started at low voltage by means of inserting series resistance according to the d.c. standard method. With alternating current supply, however, it is possible to obtain fractional voltage without sacrificing efficiency, as the step-down transformer forming part of the a.c. car equipment can be constructed with taps so that it will furnish fractional voltage without the necessity of introducing artificial starting resistance. The universal method of starting single-phase motors is, therefore, by the so-called tap potential control and the function of the control, whether it be hand-operated "K" type or multiple unit, is to successively connect the motor terminals to transformer taps of increasing potential while starting.

225. The General Electric Company markets both the hand-operated cylinder control and the multiple-unit control for use with a.c. motors. The **hand-operated control** is identical with the type "K" controller used with d.c. motors, except that advantage is taken of the fact that a.c. arcs of considerable size can be broken in the air without the aid of the magnetic blowout. Where the cars are to be operated from both a.c. and d.c. trolley with the same equipment, the hand-operated control is provided with magnetic blowout for d.c. running using the same controller without the magnetic blowout for a.c. running, unless the motor equipment be of large capacity.

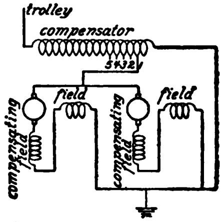


FIG. 41.—Tap control.

226. The single-phase motor differs from the d.c. series motor in having two fields, the series or energizing field and the **compensating field,** the office of the latter being to compensate for or neutralize the inductance of the armature produced by the alternating current therein.

227. The **compensating field winding** may be either short-circuited upon itself or preferably connected in series with the armature, thus making the current the same in both armature and compensating field windings. *By such an arrangement* the compensation can be carried to the extent

of raising the power factor of a single-phase motor to values closely approximating 100 per cent., and having an operating value above 95 per cent. The compensating field winding is distributed in several slots in the pole face of the laminated field magnet structure, being in all respects similar to the winding of an induction motor. As the compensating winding is either short-circuited or else connected permanently in series with the armature, it is not necessary to consider it as a factor in the motor-control.

228. The **series-field winding** of the single-phase compensated motor is connected in series with the armature, and the direction of rotation of the latter can be reversed by reversing the field winding connections similar to d.c. operation. The series-field winding may be distributed in a number of slots in the field magnet structure similar to the compensating field winding, or it may take the form of a concentrated winding in which case it is similar to the winding of a d.c. series motor embracing inwardly projecting poles. The concentrated field winding is largely used in a.c. motors of the series type, while the distributed field winding is required for motors of the repulsion or similar types. As the series-compensated motor is universally used in this country, and the repulsion and similar types are limited to special cases demanding special characteristics of the motive power, the series type motor alone will be considered.

229. The **control of single-phase motors** consists therefore, in connecting the motor terminals to transformer taps of increasing potential in order to vary the speed, while reversal is effected by reversing the series field winding connections, thus calling for practically the same combinations as demanded in d.c. series motor control. Owing to the fact that a.c. series motors are wound for potentials of approximately 225 volts per motor, and that such motors in order to meet the exactions of commerical operation must also be adapted to run with 600 volt d.c. current, it requires some additional features in control to perform this double service of a.c. and d.c. control.

230. The **General Electric a.c. motor-control** when used in connection with a.c. running only, needs no special mention other than the above, as it follows very closely along standard d.c. lines. When both a.c. and d.c. running are to be accomplished with the same control it is necessary to effect the following changes when changing from a.c. to d.c. and vice versa.

Change main line fuses or circuit-breakers.

Change lightning arresters.

Change motor field winding connections.

Change transformer taps to resistance taps.

Incidental changes in car wiring connections.

To effect these changes with a minimum amount of delay, all the necessary contacts are concentrated upon one cylinder in an auxiliary controller, so that a single movement will effect all changes simultaneously.

231. The **commutating switch** is designed to make all necessary change, and resembles in appearance and size a K-28 controller. It comprises a cylinder carrying contacts against which press stationary fingers connected to the several circuits.

232. The **master controller** is entirely similar to the d.c. master controller and needs no comments. Its office is to energize the train wires in proper sequence, and current of proper potential is obtained from transformer taps.

The **contactor** is similar to the d.c. contactor, except that it is designed for operation on both a.c. and d.c., and therefore, has its magnetic parts laminated. These contactors connect the motors with transformer taps or with starting resistance grids, depending upon the character of the supply current.

233. The **compensator** or single-coil step-down transformer is wound for 3000, 6000 or 10,000 volts trolley potential. Upon its grounded side there are several taps brought out to facilitate starting, and it is customary to connect two motors in series when operating a.c. in order to approximate 500 volts input and thus reduce the size of the contact surface required in contactors. The compensator is encased in a corrugated iron case containing oil and is self-cooled.

234. The **air compressor** is geared to a single-phase motor **wound for** operation with 500 volts a.c. or d.c. current, and it is customary to wind the motor fields in two parts connected in multiple for a.c. and in series for d.c.

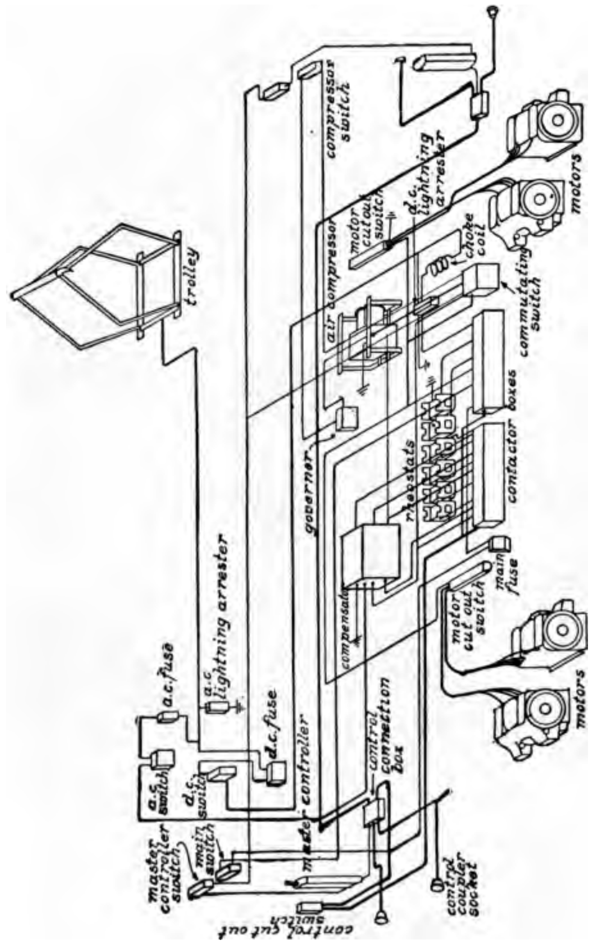


FIG. 42.—Arrangement of S. G. E. type M control on car.

running these changes being effected through the medium of the commutating switch.

235. The **current collector** or trolley is of the scraper or roller type, ***pneumatically* operated** so that the operator will not come in contact

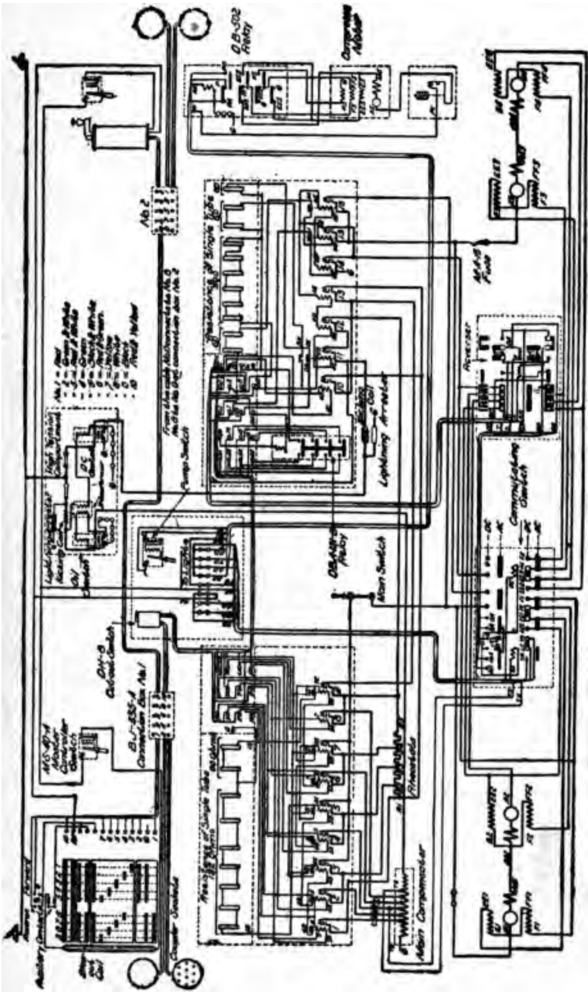


FIG. 43.—Circuit diagram of S. G. E. type M control on car.

with high voltage parts. The ordinary trolley wheel can be used for 3300 volts if it is mounted upon especially insulated base, but the use of trolley pole and cord is objectionable for high potentials and such trolleys are pneumatically operated.

236. In **changing from a.c. to d.c. trolley** and vice versa, it is necessary to guard against the possibility of wrong connections upon the car for the current received, that is, to prevent disaster should connections be made for 600 volts d.c. operation and accidental contact be made with 6600 volts a.c. trolley. To guard against this, the main switch of the d.c., a.c. car equipment is provided with a retaining coil so designed that it will open when the motor current is interrupted. Where a.c. and d.c. trolley sections adjoin, a dead section is left between the two for a length not exceeding a car length, so that a car may pass from one section to the other at full speed, in which case the main car switch opens on the dead section through lack of power to operate the retaining coil, and will reset automatically for a.c. or d.c. operation as the case may be, after leaving the dead section.

237. The **Westinghouse a.c. motor-control** is very similar to the d.c. unit-switch control except that the magnetic structure on the unit switches must be laminated, and the introduction of a commutating switch is required as described above to effect necessary changes in circuit connections for a.c. or d.c. operation.

All **circuit connections** for the unit-switch control are practically the same throughout for both d.c. and a.c. operation.

Separate trolleys are used for a.c. and d.c. operation, and high-potential wires are enclosed in metal tubing thoroughly grounded in order to ensure safety to operator and passengers.

238. When passing from one compensator tap to the next it is evident that any metal contact bridging the gap between the two will cause a short circuit in the active transformer winding, and hence, the Westinghouse a.c. control is so constructed that it introduces an inductance called a **preventive coil** when passing from one compensator tap to the next. The General Electric a.c. control accomplishes the same result by inserting a non-inductive resistance.

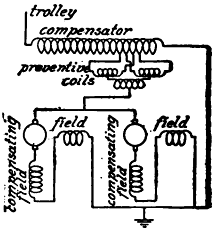


Fig. 44.—Westinghouse tap control.

239. Owing to the fact that the a.c. motor characteristic is more drooping than even that of the d.c. series motor, fewer **starting points** are **required for a.c. control.** The General Electric Company use five steps and the Westinghouse use six steps when the speed does not exceed 40 to 45 miles per hour maximum. As each point on the controller with potential tap control constitutes a running point at full efficiency, it is not necessary to use series-parallel connection of motors as is done with d.c. motors.

TYPES OF RAILWAY MOTORS.

240. The **standard railway motor** is the d.c. series motor wound for 500 to 600 volts, the latter being universally recognized as standard for large sizes. Armature and field windings are connected in series so that the current is the same in both.

All **motors** designed **for street, interurban and rapid transit** car or train **service** have four field poles, the structure being entirely enclosed with hand hole covers making it water proof. Such motors transmit power by single-reduction gear, motors being suspended at one end upon the car axle and spring suspended at the other end.

For **locomotive work** the General Electric Company has brought out a two-pole **gearless motor,** which design is also adapted for high-speed single-car service calling for large motor outputs.

The **two-pole series motor** is especially adapted for very **high speed service** and minimizes cost of repairs as well as operates with decreased

noise and greatly increased efficiency for express service. For further description of gearless motors see locomotives.

241. The **single-phase motor** has been developed along several lines of which the series-wound compensated motor is the one universally used in the United States.

The motor is identical in construction with the d.c. series motor, except that it is necessary to introduce a compensating winding in the face of the field magnet, whose office is to compensate or neutralize the inductance of the armature caused by the alternating current flowing therein.

242. This compensating field may be either **conductively or inductively** produced, depending upon whether the winding is traversed by the main motor current or by the current produced in its own short-circuited winding by the alternating armature flux. So far as concerns operation from a.c. supply, one form is about as efficient as another, but the conductive compensation is an aid when the a.c. motor is called upon to operate d.c.

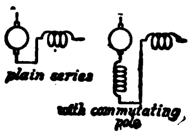


FIG. 45.—D.c. series.

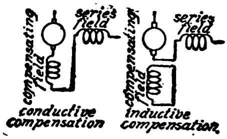


FIG. 46.—A.c. series.

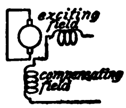


FIG. 47.—Repulsion.

243. As the armature current is alternating, there is a short-circuit developed when brushes touch two commutating segments at once. This **short circuit** is very large **at starting**, being reduced to a reasonable amount when running at full speed. To reduce the amount of this short-circuit current, and better the low-speed commutation, the a.c. compensated motor is sometimes provided with high-resistance leads connecting armature winding with commutator bars. Such leads have been found unnecessary in motors of 150 hp. capacity and less, but are desirable in a.c. series motors of larger capacity.

244. The **repulsion motor** as developed by Thomson and perfected during the past three years is shown in Fig. 47. The field winding is very similar to the field winding of an induction motor. The armature is an ordinary series-wound armature short-circuited upon itself. The repulsion motor is very similar in its operating constants to the single-phase com-

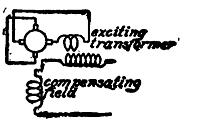


FIG. 48.—Winter-Eichberg.

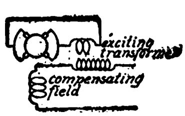


FIG. 49.—Latour.

pensated motor, but cannot be used for speeds much higher than 150 per cent. of synchronism, owing to the imperfect commutation at the higher speeds. It has the advantage of having its field circuit distinct from the armature circuit, hence, permitting of a field winding of any potential best suited for control or operation. With this type of motor it is possible to operate 3000 volts direct on the field winding if desired.

Owing to its imperfect commutation at the higher speeds, this motor is best adapted for application to slow-speed freight locomotive service.

245. The **Winter-Eichberg motor** is a form of repulsion motor in which the armature excites itself through a current transformer. The field winding is distributed while the armature winding is short-circuited upon itself, having two sets of brushes, one set being the main armature brushes the other set the exciting brushes operating in series with the current transformers shown in Fig. 48. The motor has the advantage of being

used with potential control or with manual control by shifting the brushes, and has the disadvantage of requiring a double set of brushes on the commutator. This type of motor is more limited in its field of application than the series-compensated motor.

246. In the Latour motor, which is a modification of the Winter-Eichberg motor the armature winding is short-circuited in part only, rather than through diametrically opposite brushes, with the result that the armature I^2R loss is reduced. This type is limited in its field of application to special cases.

247 The three-phase induction motor has all the characteristics of a d.c. shunt or constant-speed motor, and comprises a three-phase primary winding either star or delta connected, with a three-phase secondary winding either star or delta connected, the latter terminating in collector rings across which non-inductive resistance is inserted during the accelerating period after which the collector rings are short-circuited. The induction motor may be wound for the trolley potential if desired, as the potential of the secondary winding is entirely independent of that of the primary. The constant speed characteristic of this type of motor is especially adapted for duty ot a constant nature, such as haulage over a regular profile, either level or up a uniform gradient, in other words, where there is no combination of slow-speed grade haulage and high-speed level service.

248. The single-phase induction motor has been used for railway purposes on experimental roads, but owing to the zero starting torque of this motor it is necessary to operate it in conjunction with an auxiliary starting device and throw the motive power into action by mechanical clutches or other means after full motor speed has been obtained. This type of motive power is very limited in its field of application.

BRAKING

249. In order to bring a moving train to a stop, it is evident that some external force opposed to the motion of the train must be applied. The **ideal force** would be one which could be applied at the center of gravity of the car, thus producing no tendency for the car to rotate, and which would be sufficient to stop the train in case of emergency in the shortest possible time without undue shock to passengers or equipment. With the exception of a few instances, such as short cable roads up a mountain side, the only available force which may be utilized in stopping a train is the friction which exists between the wheels and the rails. This force besides being applied at the lower rim of the wheel and consequently not at the center of gravity of the car is also a variable quantity of uncertain magnitude and therefore not an ideal retarding force. For instance the **adhesion** between a dry rail and wheel may be equal to about 30 per cent. of the pressure between wheel and rail, whereas with a wet rail it may be only half that amount. The addition of sand to a slippery rail will increase the adhesion from 15 per cent. to about 25 per cent. of the weight on the rails, and this amount can usually be relied upon in making emergency stops. This force of 25 per cent. of the weight on the rails applied to a car will produce a retardation equal to one quarter the acceleration of gravity, or 8.04 feet per second, or nearly 5.5 miles per hr. per second. If it were possible to apply this force instantly and uniformly throughout the stops a stop from an initial speed of 60 miles per hr. could be made in about eleven seconds, or in a distance of 480 feet. This force, however, is only available when the wheels are rolling on the rails, for as soon as slipping occurs the adhesion rapidly decreases. Therefore the force which opposes the revolution of the wheels, namely the brake-shoe friction, must never exceed that which is keeping the wheels turning, namely the adhesion between the wheels and rails. This opposing force is obtained in several different ways, the most familiar being by applying brake shoes to the rim of the wheels with considerable force by means of hand or power brakes. Another method which is applicable in electric traction is known as electric braking as distinguished from mechanical braking, and consists in opposing the revolution of the wheels with the counter torque of the motors or by the friction of electrically operated brake discs

250. About the first systematic tests to determine the value of the coefficient of friction between brake shoes and wheel, and between *wheel and rail* were conducted by Sir Douglass Galton and Mr. George

Westinghouse in 1878 and 1879 on the London, Brighton & South Coast Railway, England. A report of these tests appears in the proceedings of the Institute of Mechanical Engineers of London, for April, 1879. The following table gives the results of these tests:

251. Coefficient of Friction at Various Speeds. Cast-Iron Brake Blocks on Steel Tires.

Number of Experiments from which the Mean is taken	Velocity		Coefficient of Friction		
	Miles per Hour	Feet per Second	Extreme Maximum	Observed Minimum	Mean
12	60	88	.123	.058	.074
67	55	81	.136	.060	.111
55	50	73	.153	.050	.116
77	45	66	.179	.080	.127
70	40	59	.194	.088	.140
80	35	51	.197	.087	.142
94	30	44	.196	.098	.164
70	25	36½	.205	.108	.166
69	20	29	.240	.133	.192
78	15	22	.280	.131	.223
54	10	14½	.281	.161	.242
28	7½	11	.325	.123	.244
20	Under 5	Under 7	.340	.156	.273
	Just moving	Just moving			.330
Fleeming Jenkin (steel on steel)	.0002 to .0086		.337	.365	.351

Rennie. Static Friction under

Pressure of 180 lb. per square inch.........300

Pressure of 336 lb. per square inch.........347

252. From the above values Mr. R. A. Parke has developed the following **formulas** to represent the law of **variation of the coefficient of friction with speed.**

From the mean values $$f = \frac{.326}{1 + .03532\,S},$$

from the maximum values $$f = \frac{.382}{1 + .02933\,S},$$

where f = coefficient of friction,

S = speed in miles per hour.

The latter formula gives values corresponding more nearly to recent experiments.

253. Coefficient of Friction as Affected by Time.*

Miles per Hour	Commencement of Experiment†	After 5 seconds	After 10 seconds	After 15 seconds	After 20 seconds
20	.182	.152	.133	.116	.099
27	.171	.130	.119	.081	.072
37	.152	.096	.083	.069	
47	.132	.080	.070		
60	.072	.063	.058		

*Sir Douglas Galton has also published the following values of the coefficient of dynamic friction as affected by time of brake application.

† The figures in this column are somewhat different from those that have just been given in the altered table, because they resulted from the average of fewer experiments; but the effect of time in reducing the coefficient of friction may be accepted as correct.

254. Mr. R. A. Parke's **formula** representing the **decrease of the coefficient of friction with length of brake application** is as follows:

$$f' = \frac{1 + .00472\ T}{1 + .000239\ T},$$

wherein f is the coefficient of friction at beginning of application; f' the coefficient of friction after brake application of T sec.

255. Elaborate tests were made in 1895 and 1896 by the Master Car-Builders Association to determine the relative advantages of different kinds of brake shoes on steel tired and cast-steel wheels in respect to wear and coefficient of friction. The results of these tests, however, showed such lack of agreement as to emphasize the difficulty of obtaining consistent data.

256. The absence of more extended observations and the complex nature of fluctuations of the coefficient of friction makes it impossible to formulate a practical mathematical equation which will determine the rate of retardation under varying conditions. However, the results of the tests shown in the tables above indicate a **law of variations** which may be briefly stated as follows regardless of the materials used.

(a) The coefficient of friction increases with the decrease in speed;

(b) Decreases with the increased distance through which brakes are applied, and

(c) Decreases with the increase of pressure.

257. It is evident therefore that in order to obtain a **uniform braking effort** throughout the stop, the brake-shoe pressure must be varied to compensate for the fluctuations in the coefficient of friction, that is, the brake-shoe pressure must be decreased as the diminution in speed increases the coefficient of friction, and increased as the distance of brake application decreases the coefficient of friction, and further increased to compensate for the decrease of the latter with increased pressure.

258. For certain speeds the increase in coefficient of friction with decrease in speed is practically neutralized by a decrease due to increased distance of frictional contact, but for lower speeds the increase from the former cause is more rapid than the decrease from the latter, necessitating an almost abrupt decrease in brake-shoe pressure near the end of a stop to avoid slipping the wheels on the rails and discomfort to passengers.

259. For the same pressure, the coefficient of brake-shoe friction at 60 miles per hr. is only about half that at 20 miles per hr. It is therefore evident that an **emergency stop** for high speed is less efficient than that from low speed, since an emergency application implies that the maximum pressure which will not slip the wheels near the end of the stop is instantly applied at the very outset. A considerably shorter stop may be made if the pressure applied during the earlier periods of the stop is greatly in excess of that which will slip the wheels at low speed, but in the absence of the motorman's skill some means must be provided to decrease the pressure near the end of the stop in order that the limits of rail friction will not be exceeded and the efficiency of the stop thereby decreased. This provision, however, requires additional apparatus, which on general principles is objectionable, unless the showing is so favorable as to warrant further complications.

260. Thus far attention has been devoted to outlining methods for overcoming the obstacles which are presented by the complex nature of the fluctuations of the coefficient of brake-shoe friction and which prevent the utilization of the theoretically possible retarding forces. The nature of the application of these forces imposes difficulties which prevent the full utilization of the weight on the trucks and wheels, thereby directly affecting the braking force.

261. At the present time it is customary to equip double-truck cars with either two motors or four motors, depending upon the nature of the service. In the former case both motors are usually placed on one truck thus permitting a lighter truck to be used as a trailer.

The ***pressure*** which may be **safely applied to the wheels** of the motor

truck without causing the wheels to slip cannot be applied to the wheels of the trailer truck, hence, the brake rigging must be proportioned so that the greatest portion of the braking is done upon the wheels of the motor truck. Considering, however, the case where the normal distribution of weight is equal for all wheels, it is found that during braking a greater pressure may be applied to the wheels of the forward truck without causing them to slide than can be applied to the wheels of the rear truck. The explanation is somewhat simplified when considering single-car operation, since draw-bar forces may be eliminated.

262. The **resultant of all the parallel forces,** which act on the elementary masses of the car tending to keep it in motion, is equal to the sum of all these forces and acts at the center of gravity of the car and in the direction of motion. Directly opposed to the motion of the car is the wind pressure which also acts on the elementary surfaces, hence the re-

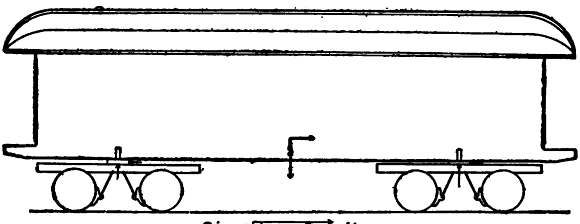


Fig. 50.—Braking-stress diagram.

sultant wind pressure acts at approximately the center of gravity of the car; but being sufficient to cause only a slight retardation compared to that obtained with the brakes its effect has been neglected in this consideration. The retarding force of the brakes acts at the surface of the rail; and as all parts of the structure are retarded equally, the king pins must transmit the force required to produce the same retardation in the car body as is produced in the truck. The total retarding force less the amount required for retarding the wheels and trucks therefore acts at the points of support which are somewhat lower than the center of gravity of the car body. The moment of these forces about the center of gravity of the car is balanced by the moment produced by the increased pressure of the forward truck acting upward through the point of support. At the same time the weight on the rear truck is decreased.

263. The **distribution of weight on the wheels** of each truck is affected in the same way except that the retarding force transmitted through the king pins to the car body also reacts to further increase the pressure on the front pair of wheels of each truck.

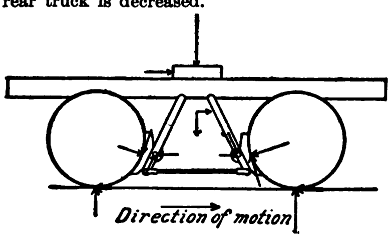


Fig. 51.—Stress diagram.

Because either end of the car may at some time become the rear end, it is essential that the brake-shoe pressure be kept the same for all wheels, which necessarily restricts the **maximum pressure** which can safely be employed to that which will not slip the wheels with the least weight. In the case of the eight-wheel passenger car, the effective wheel pressure which may be utilized in braking is only about 85 per cent of that permissible with the total weight on the wheels.

264. On account of the **stored energy in the revolving wheels,** gears and armatures which may amount to 5 or 10 per cent. of the total stored energy of the car, a consideration of the effect of these forces upon the truck through the brake hangers is essential. With outside-hung brake-shoes the friction between brake shoes and wheel is downward for the leading wheels, thereby causing compression of the forward springs of the truck; and upward for the trailing wheel, thereby relaxing the rear springs of the truck. The recoil of the forward springs results in the backward motion of the car body so disagreeable to passengers at the instant of stopping. With inside-hung brake-shoes the brake-shoe friction is upward through the hanger links of the forward portion of the truck and downward through the hanger links of the rear portion of the truck, thus tending to neutralize instead of aggravate the effect of the rotating influence of the car body. The problem of proportioning the length of brake-shoe hangers and the proper inclination of the same to the tangent at the point of contact of the center of the shoe for exact compensation for the rotating influence of the car body, is too involved for presentation here. For this reason reference is made to Mr. R. A. Parke's excellent paper in the proceedings of the American Institute of Electrical Engineers, Vol. 22, Dec. 1902.

265. A common form of **hand brake** consists of a vertical shaft at each end of the car fitted at the top with a ratchet handle or crank, or geared to a hand wheel whereby the motorman can wind up a chain, one end of which is fastened to the lower end of the vertical shaft and the other end to a rod which connects with a system of brake levers. By means of a pawl (or dog) which engages in a ratchet wheel on the vertical shaft near the floor of the car, the motorman is enabled to hold a pressure on the

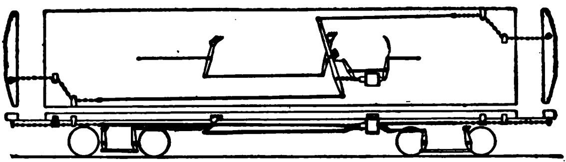


Fig. 52.—Diagram of brake rigging.

brake shoe while he gains a more favorable purchase for applying more pressure, or until such times as he desires to release the brakes. This brake has been found capable of supplying sufficient braking power for the safe control of light cars running at moderate speed, but for heavy cars and high speeds the physical effort and time required to properly apply the brakes render it necessary to provide other means of supplying the proper force in a minimum length of time. Hand brakes, nevertheless, are always provided as an additional safeguard, even though the cars may be equipped with power brakes, as it is always customary to set up the hand brakes on all cars when they are left standing.

266. Air brakes have been universally adopted in some form or other on all steam roads for braking both passenger and freight trains, and the results have been attended with such success that modifications and improvements of the old steam railroad air brake system have been developed and adopted by a vast majority of electric lines operating heavy high-speed interurban cars either singly or in trains. On account of the varying character of the service on different electric roads, it has been found necessary to develop several systems, or modifications of the same system which will be best adapted for the service in hand.

267. The most familiar types at present are known as the following:

The straight air-brake system recommended for single car operation only;

The emergency straight-air system suitable for two-car operation, particularly when one is operated single most of the time and with a trailer added during rush hours;

The automatic air brake suitable for electric trains of three cars or more;

The combined straight and automatic air brake designed for locomotive operation, no matter whether steam or electric, and

The electropneumatic air brake at present in an experimental state, but particularly adapted to train operation, inasmuch as the time element in the application and release of the brakes on the rear end of a long train is practically eliminated.

268. The straight air-brake system consists essentially of a source of compressed air (either a tank filled at intervals from a compressor at charging stations, or an air compressor, motor or axle driven, located upon the car); a reservoir which receives the air from the charging tanks or from the compressor and in which the pressure is maintained practically constant by means of a reducing valve, or by a governor which automatically controls the operation of the compressor; a brake cylinder, the piston of which is connected to a system of brake levers in such a manner that when the piston is forced outward by air pressure the brakes are applied; an operating valve mounted in each vestibule by means of which the compressed air is either admitted or released from the brake cylinders; a pipe system connecting the above parts, including cutout valves, extra hose, and angle fittings between cars. In order to prevent any possibility of accumulating an excessive pressure, a safety valve designed to open at 100 lb. per sq. in.

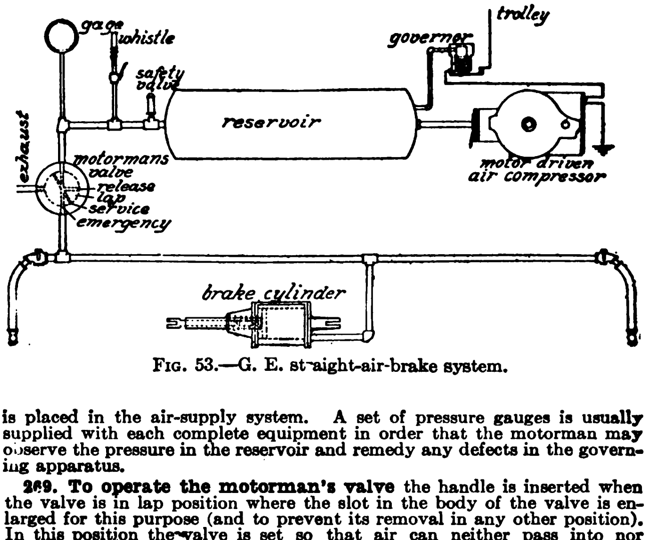


FIG. 53.—G. E. straight-air-brake system.

is placed in the air-supply system. A set of pressure gauges is usually supplied with each complete equipment in order that the motorman may observe the pressure in the reservoir and remedy any defects in the governing apparatus.

269. To operate the motorman's valve the handle is inserted when the valve is in lap position where the slot in the body of the valve is enlarged for this purpose (and to prevent its removal in any other position). In this position the valve is set so that air can neither pass into nor out of the brake cylinder. Moving the handle to the left places the valve in full release, that is, connects the brake cylinder to the atmosphere and allows the air which holds the brakes applied to escape, and the spring which is opposed to the air pressure restores the piston and releases the brakes. After the brakes have been released the valve is returned to lap position, which is the normal running position. To partially release the brakes, which is necessary in braking in order to prevent shocks as the car stops, the handle is moved to the right and quickly returned to lap. This reduces the pressure on the brake shoes, but does not entirely release them.

270. To apply the brakes for a **service stop**, the handle is moved to the right a little past the lap position, then back to lap. This connects the

reservoir with the brake cylinder through a small opening in the valve, then holds the pressure constant until it is necessary to release or apply more pressure. Moving the handle further to the right connects the reservoir to the brake cylinder through a large opening, thus causing the cylinder to fill rapidly and **instantly apply** the **brakes** with maximum pressure. Sand is usually applied to the tracks as soon as the handle is turned to emergency to avoid skidding the wheels.

271. In **descending grades** a light application of the brakes should be made and the handle returned to lap. A sufficient length of time should be allowed for car to feel the effect of the brakes before applying more pressure. If speed is higher than desired a second light application should be made and operation repeated as often as necessary until the desired speed is obtained, or until the car has left the grade.

272. The **straight-air system** of air brakes, although only **recommended** for single-car operation, may be used when operating with a trailer. The equipment for trail cars consists of a brake cylinder and system of levers similar to the ones on the motor car, a length of pipe running the

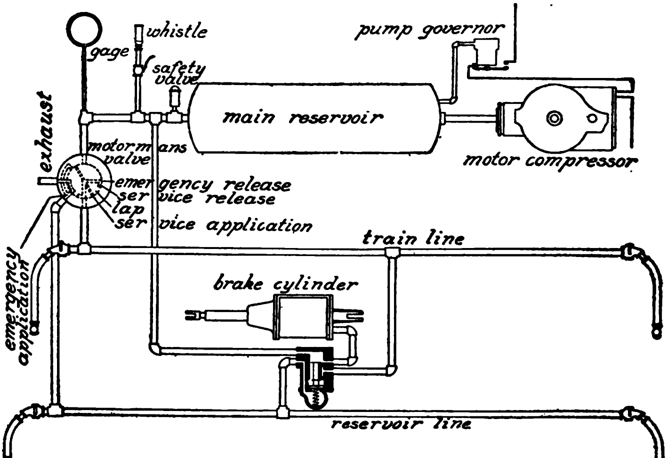


FIG. 54.—G. E. emergency straight-air brake system.

entire length of the car and provided with hose couplings and cutout cocks for connections to the forward and rear cars. In connecting up trail cars, all the hose couplings must be thoroughly united to insure that air will apply throughout the entire train. All the cutout cocks must be opened except those on the rear of the last car, and the front of the first car, which must be closed.

273. So far as single-car operation is concerned, the straight air-brake system is very satisfactory, as the desired flexibility in the matter of graduations of applications and release of the brakes with due regard to the passengers standing can readily be secured, and this apparatus is usually so simple in construction that the motorman may become familiar with its operation to such an extent that **accurate stops** may be secured with a minimum amount of instruction. In trains of considerable length, however, the response of the brakes on the rear cars is too slow, since all the air must pass from the main reservoir on the front car through the opening in the motorman's valve to the brake cylinders of each car. As the addition of each car adds to the volume of the brake system, the main reser-

voir on the first car must be considerably increased in order that the pressure will not be reduced to such an extent that the brake application will not be sufficient and result in overrunning the desired stopping place. These latter objections would not be sufficient to prevent the use of this type of air brakes on short trains of two or three cars, were it not for the fact that a broken hose connection or leaky train pipe renders the brakes on the whole train inoperative.

274. The emergency straight-air brake differs from the straight-air brake in the details of the motorman's valve and in the addition of an emergency valve and reservoir line which connects the motorman's valve with the emergency valves. In the case of a trail car, an auxiliary reservoir is also added as shown in Fig. 55.

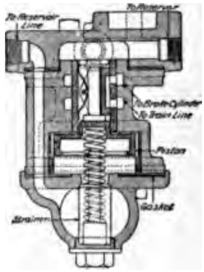


FIG. 54A.—Emergency valve.

In the ordinary operation of single cars or short trains, the emergency valve is seldom brought into play. It is necessary, however, to provide a short direct passage from the reservoir to the brake cylinder in order to ensure the quickest possible action in time of emergency and to provide some means of automatically braking the rear cars should a break occur in the train line. At other times when it is desired to make a service application or release, the air is admitted or exhausted through the motorman's valve the same as in the straight-air brake.

275. With the **motorman's valve** in the **emergency position,** it allows air to escape from the reservoir line and causes the reservoir pressure, which is above that in the emergency valve, to compress the spring which holds it in its normal position, thus opening a port in the casing of the valve to the brake cylinder for the direct passage of the reservoir air. At the same time all communication with the train and reservoir lines is cut off. To release the brakes, therefore, it is necessary to first return the emergency valve to its normal position by recharging the reservoir line

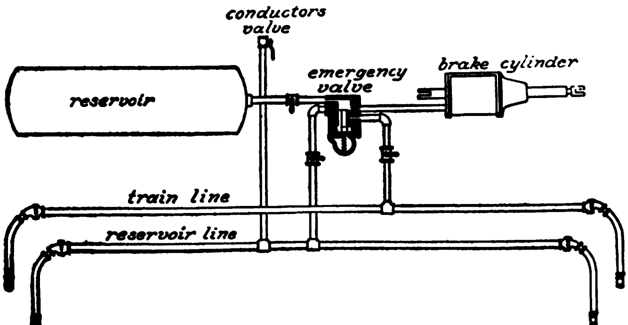


FIG. 55.—G. E. emergency straight air brake for trail cars.

to the reservoir pressure, which allows the spring under the valve to return it to its original position, then brakes can be released the same as after a service application by exhausting the air from the train line. The recharging of the reservoir line is accomplished by moving the motorman's valve to emergency release position at the extreme left of the slot in the body of the valve where a connection is made between the main reservoir and the reservoir line as well as one between the train line and atmosphere. With the emergency valve in normal position there is a direct passage to

the train line and brake cylinder, and the service applications and release are made by increasing or decreasing the pressure in the train pipe.

276. In the case of a **trail car** the **auxiliary reservoir is charged** during emergency release by the air pressure equalizing on both sides of the slide valve through the charging grooves in the valve casing. At other times it is charged from the main reservoir through the charging grooves in the emergency valve on the motor car.

In case of accident to the reservoir line the air can be exhausted from the auxiliary reservoir and the train operated on straight air without interrupting the service. An accident to the train line has no effect upon the action of the emergency valve which still can be operated as ordinarily by throwing the motorman's valve to the emergency position. As this system has the straight-air brake principle most prominent it is subject to the same objections which prevent the use of the straight-air brake on longer trains, namely the time limit. For this reason, the automatic air-brake is used on trains of three or more cars.

277. The automatic air-brake differs from the straight-air brake in that the former requires a decrease in the train-pipe pressure to apply the brakes, and an increase in pressure to release them, whereas in the latter, air is admitted to the train pipe to apply the brakes and exhausted to release them.

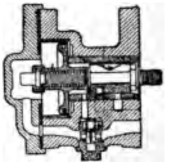


Fig. 56.—S-1 triple valve.

278. The **apparatus required** for this system in addition to that already mentioned for the straight-air brakes is as follows: A set of duplex pressure gauges which indicate simultaneously the pressure in the main reservoir and in the train pipe; an auxiliary reservoir for storing the air used by each car in braking; a triple valve, the function of which is to admit air from the auxiliary reservoir into the brake cylinder and to release it therefrom (in release position, the auxiliary reservoir is recharged), and an air-whistle reservoir with suitable check valve for supplying air to the air whistle.

279. This system is capable of a great many **refinements** which may be added or omitted as requirements of a particular service may prescribe. The main points of difference between particular automatic air-brake equipments will generally be found in the details of the triple valves, and the addition of pressure maintaining and reducing valves, which are essential in certain classes of grade work in order to prevent brakes leaking off. These particulars have been intentionally omitted from this consideration to avoid undue complexity. Two forms of triple valves, however, need to be considered here inasmuch as the plain triple valve, Fig. 56, is only used on comparatively short trains, about five cars in length, whereas the quick-action triple valve, Fig. 57, is designed to be used on much longer trains.

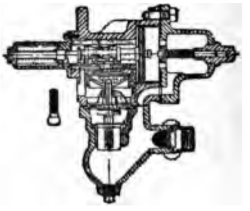


Fig. 57.—K triple valve.

280. For the **emergency position** shown in diagram, Fig. 57, the train line is open to the atmosphere, allowing auxiliary reservoir pressure on the right of the slide-valve piston to force it to the left against the graduating spring, compressing it and uncovering the brake-cylinder port, thus permitting air to flow from the auxiliary reservoir directly into the brake cylinder, at the same time the ports leading to the atmosphere and to the train pipe are closed.

281. To release the brakes, the main-reservoir air is admitted through the train to the chamber at the left of the slide-valve piston, forcing it to the right and connecting the brake-cylinder port to the exhaust port, at the same time air at the main-reservoir pressure raises the check valve and recharges the auxiliary reservoir to main-reservoir pressure.

A **graduated release** of the brakes may be obtained with this type of valve by piping the exhaust from the triple valve to the motorman's valve

where a movement of the valve handle will release the air the same as in the straight-air brake.

282. A service application requires only a slight reduction in train-line pressure (from 5 to 7 pounds) which is sufficient to permit the slide-valve piston to slightly compress the graduating spring and partially open the brake-cylinder port. When the auxiliary reservoir pressure has been reduced to about the same as the train-line pressure, the graduating spring will return the slide valve to lap position, closing all the ports before the

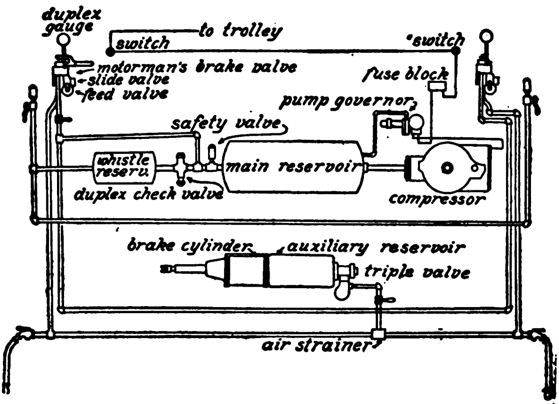


FIG. 58.—Westinghouse automatic air-brake.

brakes are fully applied. The auxiliary reservoir and brake cylinder are usually so proportioned that the brakes are fully applied when the brake piston displacement is sufficient to reduce the auxiliary reservoir pressure about 15 lb. Therefore, a train pipe reduction greater than 15 lb. fully applies the brakes and is wasteful of air as the train pipe and the auxiliary reservoir must be fully charged after each application.

283. The quick-action triple valve shown in Fig. 57 is designed to be used on freight trains of considerable length, its function is to apply and release the brakes on the rear cars so quickly that the running in and out of the slack is avoided. Fig. 59 is a diagrammatical section of the triple valve shown in Fig. 57. In the full release position shown, air is allowed to pass from the brake cylinder through ports in the slide valve, the same as in the plain triple valve. The auxiliary reservoir is charged through grooves around the slide-valve piston and through the raised check valve and uncovered port in the slide valve.

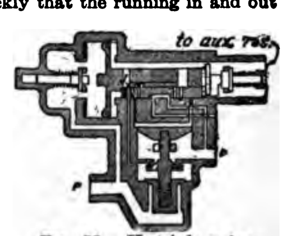


FIG. 59.—K. triple valve.

284. In release position the decrease in train line pressure allows the valve piston to move to the left closing the charging grooves and feed port, J, and exhaust port, P. Just previously to the valve piston striking the graduating stem, a cavity in the grading valve on top of the slide valve connects ports which allow communication from the brake cylinder to the emergency chamber and train pipe. The piston in the emergency chamber is only loosely fitted so that the air which is admitted from the train pipe to the unseated check valve passes

into the brake cylinder before communication is established between the auxiliary reservoir and the brake cylinder. Owing to the friction in the train pipe a reduction of air pressure at the front end of the train is not felt at the rear end until some time later, thus the venting of the train pipe at each car results in hastening the reduction for each car following; at the same time requiring a less reduction at the engineer's valve to apply the brakes with a given pressure since the auxiliary reservoir is not required to supply all the air to the brake cylinder.

285. When the brake-cylinder pressure is reduced below that in the train line, the slide-valve piston moves to the right with the graduating valve and closes all ports leading to the brake cylinder. The tendency for the brake-pipe and auxiliary-reservoir pressures to equalize through the connections to the brake cylinder is prevented by the proportioning

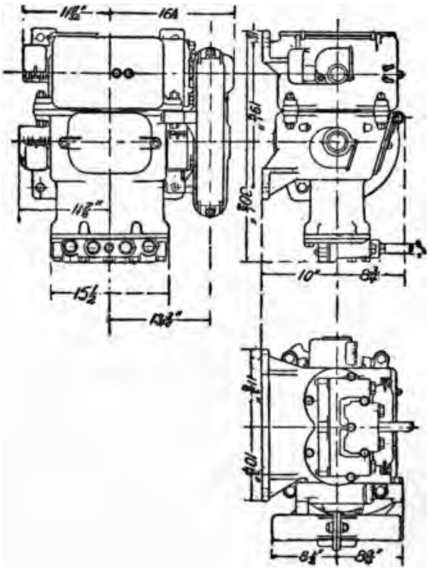


Fig. 60.—Air compressor.

of the respective ports, so that the auxiliary-reservoir pressure decreases faster than the brake-pipe pressures and insures the travel of the piston to the right.

286. In **retarded release** the train line is quickly re-charged, forcing the valve piston to the extreme right, thus preventing the re-charging of the auxiliary reservoir through the charging grooves before opening a small port in the slide valve, thus permitting the train-line pressure to raise the check valve and slowly re-charge the auxiliary reservoir. The function of the charging device (shown on the outside of the valve in Fig. 57) is to prevent the inertia of the slide valve forcing it to the extreme right of its travel when the valve piston is brought up against its stop. The restricted area at the left end of the exhaust cavity of the slide valve partly closes the exhaust port and allows the brake-cylinder air to flow slowly into the atmosphere. On account of the friction in the train pipe, it is *impossible to re-charge* the train line at the rear of the train faster than

the air will flow through the charging grooves of the triple valves, hence only the triple valves of the foremost cars move to retarded release, the others remaining in full release, thereby releasing the brakes on the rear cars quickly.

287. The sudden reduction of train-pipe pressure in **emergency position** of the engineer's valve moves the slide-valve piston to the left compressing the graduating spring and opening a port directly to the brake cylinder and another to the emergency chamber unseating the emergency valve; at the same time the train-line pressure opens the check valve and air flows from the train-line directly into the brake cylinder, applying the brakes with maximum pressure. The quick venting of the train line insures the rapid serial action of the brakes on the rear cars.

288. The combined straight and automatic air-brake, as the name implies, consists of two sets of motorman's valves for the control of each system. The straight air-brake operating with pressure between 55 and 70 lb. per sq. in. applies and releases the brakes on the front car independently of the brakes on the other cars. The automatic brakes operate with air pressure from 100 to 110 lb. per sq. in. and apply the brakes on the remainder of the train independently of the brakes on the front car. The chief advantage of such an arrangement is the possibility of holding the brakes on the locomotive applied while the train brakes are released for the purpose of re-charging the auxiliary reservoirs.

289. The electropneumatic system is practically the same as the present automatic system, except that the valves are operated by solenoids in much the same way as the contactors in the multiple-unit train control. At the present time air control is retained as a safeguard in case of failure of the electric control. With electric traction, the possibilities of this system seem to be unlimited and automatic retardation as well as acceleration is quite feasible.

290. The air reservoirs should have a **capacity** sufficient to supply air for three or four applications without reducing the pressure more than 12 to 15 lb. Otherwise every ordinary application of the brake will throw the compressor into action, thus keeping the latter in a constant state of starting and stopping, and causing unnecessary wear to both compressor and governor. The Westinghouse Traction Brake Company recommended the following sizes of reservoirs:

With	8-in.	brake	cylinders	use	16 in. x 48 in.	reservoirs.
"	10 "	"	"	"	16 in. x 60 in.	"
"	12 "	"	"	"	16 in. x 72 in.	"

The lengths given above are over all.

291. These reservoirs are fitted with drain cocks and should be drained frequently in order to prevent any water, oil, or dirt, which is brought in by the compressed air, being carried further into the brake system. If allowed to stand for several days, the reservoir will fill with water, thereby reducing its capacity, and will also allow moisture to pass into the piping system and collect in pockets where it will be likely to freeze in cold weather.

292. Track brakes have been developed to be operated in connection with either power or hand-brakes, the distinctive feature being the utilization of the power generated by the motors when properly connected to energize a powerful electromagnet, thereby drawing a suitable track shoe to the rail with considerable force. The friction between the track shoe and rail is transmitted to the brake shoes on the wheels through a system of brake levers, thereby adding to the braking effort of the brake shoes on the wheels an amount equal to the drag of the track shoes on the rails and the counter torque of the motors acting as generators. It is possible, on account of the automatic regulation of the magnetic attraction between the track shoe and rail, to utilize as great or possibly greater brake-shoe pressure than is customary with either hand or air brakes without skidding the wheels, but in practice this is seldom required and a considerably less braking pressure is customary. The friction between the track shoe and rail necessary to produce the requisite brake-shoe pressure will depend upon the design of link motion and the speed of the train; however, this

is usually greater than the braking effort exerted by the wheel brakes, and where the speed is low advantage can be taken of a high coefficient of friction which is impossible where the wheels are apt to skid as with power brakes. It is thus evident that the retardation possible with track brakes is at least twice as great as with power brakes, rendering them particularly well adapted as emergency brakes for heavy grades, which are characteristic of scenic railways, etc.

292a. It should be noted, however, that since this brake depends upon the electromotive force generated by the motors when running as generators it cannot be depended upon to hold a train on a grade or bring it to a stop unless a connection is made with the trolley for this purpose. There are various objections to resorting to this means of energizing the brake solenoid, except in an emergency, consequently the electric track brake is limited in its applications to roads where it is necessary to provide additional safeguard at the expense of considerable complications to the ordinary form of brakes.

TRUCKS AND CAR BODIES.

293. The development of the self-propelled car has led to some modifications in standard truck design. The several types of trucks all fall in two general groups—namely, the single-truck, and the double or bogie truck.

The single-truck car is intended for city street service, and where the maximum speed does not exceed 25 miles per hr. The two axles of the single-truck are rigidly aligned by side frames, so that of necessity the rigid wheel base must be short to negotiate sharp curves, thus limiting the length of car used, as too much overhang is productive of much rocking and unsafe riding, and is objectionable also when rounding sharp curves in city streets.

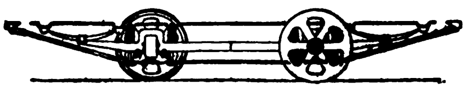


Fig. 61.—Single truck.

294. In order to provide easy riding, the car superstructure is supported upon elliptic and coil **springs** designed to take up the shock resulting from riding over uneven track. Single-truck cars are limited to a maximum length of about 30 feet overall and a maximum weight including car body and trucks, but exclusive of electrical equipment, of approximately 15,000 pounds.

295. The double-truck car is equipped with two distinct trucks joined together through the medium of the car body framing. **The swivel or bogie truck** consists essentially of two or more axles centered in common side frames joined by a cross piece or bolster carrying a center plate and side-bearing plates upon which the car body rests.

The bogie truck may comprise two or more axles mounted in a single structure, the prevalent type, however, is composed of two axles for cars weighing up to 50 tons total weight. For very high speed service or for heavy cars three-axle trucks are to be recommended.

296. The **standard four-wheel bogie truck** is built along different lines depending upon the service which it is to perform. As the weight of the car body is carried upon the cross piece or bolster connecting the side frames, it is evident that the construction of this bolster and its support offers a means of cushioning the effect of shocks given the car wheels when riding over uneven track. There are three general types of bogie trucks, namely: The rigid bolster type; the floating bolster type, and the swinging bolster type.

297. The rigid bolster type is suitable for **locomotive work** only as the cushioning effect of the car body by means of springs is not carried to sufficient length for easy riding qualities. The bolster is solidly fastened to the side frames and forms an integral part therewith. The *spring-suspended car superstructure* is sustained by means of box springs placed

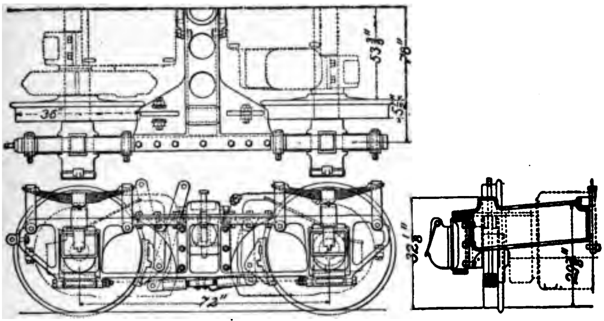


FIG. 62.—Motor truck, locomotive frame-rigid bolster.

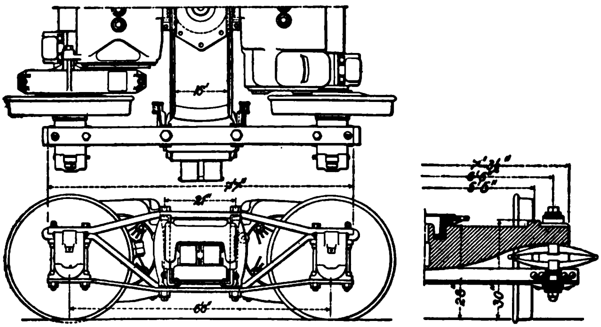


FIG. 63.—Arch-bar type—floating bolster.

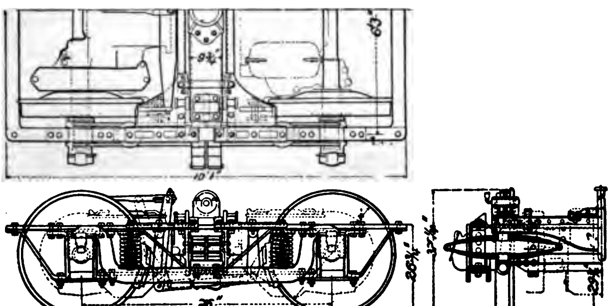


FIG. 64.—Bar frame—swinging bolster.

between the side frames and the journal boxes. These springs may be of the semi-elliptic (Fig. 62) or spiral type (Fig. 65). This type of construction offers no compensation for the swaying of the superstructure, and is therefore not adapted for high speed or passenger service.

298. The floating bolster construction comprises in part a bolster mounted upon elliptic springs resting upon the side frames. The bolster thus has an independent vertical movement and travels in ways in the side frame. This type of construction is best adapted to **locomotive trucks** designed for slow speed service, as the superstructure is not sufficiently cushioned to provide easy riding for high speed passenger service.

299. The **swinging bolster construction** comprises a movable bolster traveling in a guide or transom and mounted upon elliptic springs, a construction very similar to the floating bolster type. In the former, however, the elliptic springs do not rest directly upon the side frames, but rest in a saddle hung from the transom or side frame construction in such a manner as to provide opportunity for a transverse swing of the superstructure. This permits the superstructure to swing or roll when rounding curves and offers a very easy riding truck for high speed passenger service. To still further increase the cushioning effect, the side frames are not directly mounted upon the journal boxes but have coil springs interposed, either placed directly over the journal boxes (Fig. 65) or between the side bar and the truck frames (Fig. 64) or a combination of both.

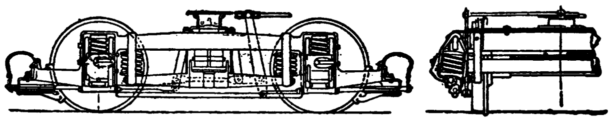


Fig. 65.—Swing bolster truck (Brill Co.).

300. The swinging bolster truck is designed for **high-speed passenger service,** and is satisfactory for speeds up to 70 or 80 miles an hour maximum. For very high speeds it is preferable to provide a bogie truck construction consisting of three axles, the two outside axles carrying less weight than the center axle, and preferably carrying no motors geared thereto.

301. The truck bolster may be made of wood or metal, and both the center plate and side-bearing plates which it carries may be ball or roller bearings, in order to reduce the friction and permit the truck to readily respond to the demands of track curvature.

The side frames may be built up of steel plates riveted together or forged or cast in a single piece. The construction is rigid and provides for good alignment of the axles.

302. Maximum traction trucks are designed for city service at speeds not much exceeding 30 miles per hour, and are useful where it is desired to mount a single motor on a truck providing for four wheels, having a short wheel base, and carrying 70 per cent. of the total car weight upon the driving wheel, which is larger in diameter than the trailing wheel. Maximum traction trucks are not suitable for high-speed service.

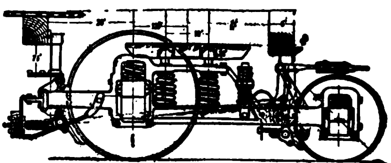


Fig. 66.—Maximum traction (Brill Co.).

303. Car bodies differ in construction according to local requirements. They may be divided into two general types, namely: open cars, and closed cars.

The dividing line between these two types is not sharply defined owing *to the introduction* during the past few years of the **convertible and**

semi-convertible type of car body which permits the complete closing in of the car body sides or partial removal thereof according to climatic conditions. The true type of open-car body is arranged with cross seats which will seat five passengers per seat and in the larger cars seating 75 passengers per car.

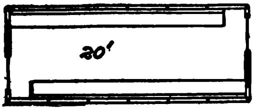


FIG. 67.—Seat capacity 24.

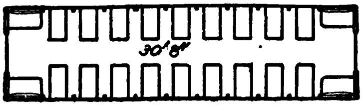


FIG. 68.—Seat capacity 44.

304. The closed-body car may be provided with either longitudinal or cross seats, the former being used in the shorter cars of 30 feet overall and under, and the latter in the larger city and suburban cars.

The prevalent type of **transverse seat** car is indicated in Fig. 68, and usually contains short longitudinal end seats in addition. Owing to the possibility of crowding at the car entrance, it has been found advisable to provide more standing room at these points, leading to a composite type of car having longer longitudinal end seats and providing transverse seats in the center portion of the car only.

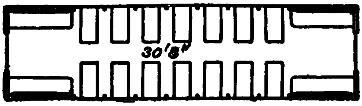


FIG. 69.—Seat capacity 44

In some instances it is necessary to provide narrow city cars and insufficient space is allowed for transverse seats capable of seating two people on the side. A modification of transverse seat car is constructed for such cases having the longitudinal aisle and providing a two passenger seat on one side and a one passenger seat on the other.

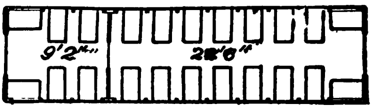


FIG. 70.—Seat capacity 44.

305. For **suburban service** it is desirable to provide a **smoking compartment** divisioned off from the main portion of the car and connected to it by a door. Such a car should preferably be run single ended with the smoking compartment in front, although it is common practice to run such cars double ended, in which case all passengers may be compelled to pass through the smoking compartment to reach the main seating portion of the car.

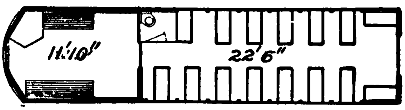


FIG. 71.—Seat capacity 37.

Owing to the necessity of taking care of baggage or express material on suburban lines many such cars are supplied with a **baggage compartment** which is also used as a smoking compartment and in addition a toilet should be provided where the run is of considerable length.

306. Many **cars are heated** with hot water instead of electrically, and the more elaborate high speed interurban cars operating over long distances provide a compartment for express matter, smoking compartment, main passenger compartment, toilet rooms, etc. The motorman's compartment is divisioned off from the baggage compartment and such cars are generally run single ended requiring the use of a loop or Y at the terminals.

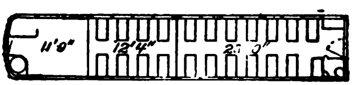


FIG. 72.—Seat capacity 46.

307. In general it may be stated that **longitudinal seat cars** are suitable only for short runs and **medium rates of acceleration**, and **transverse seats** should be used in order to provide comfort for the passenger where the **accelerating rates** are **high** or the run extended.

For certain classes of city service where the track capacity is limited and speeds are moderate, recourse may be had to a **double deck** or top-seated car. These cars are only suitable for climates having small temperature change and must be operated at low speed (25 miles per hr. or less) in order to prevent possibility of over turning. Access is had to the upper seating portion of the car by means of outside stairways leading off the car platforms.

Besides the convertible and semi-convertible type of closed cars a combination open and closed car is used for warm climates, as it offers the greatest advantages for all the year operation.

308. Data on Typical Electric Cars.

Maker	Over all Length		Length Body		Weight Body	Weight Trucks*	Type Trucks	Remarks
	ft.	in.	ft.	in.				
Brill Co.	22	0	16	0	6000	4600	Single	Closed car
" "	26	0	18	0	6940	4400	"	" "
" "	26	0	20	0	7100	4400	"	Mail car
American Car Co.	26	6	18	2	7000	4500	"	Closed car
Brill Co.	28	0	20	0	7600	4600	"	" "
" "	28	0	16	0	8350	4600	"	Double decked
" "	28	0	20	0	8950	4600	"	Combination car
" "	29	7	20	3	8000	4500	"	Closed car
Pullman Co.	29	10	20	0	9530	4800	"	" "
Stevenson Co.	32	2	22	1	7500	4500	"	" "
Brill Co.	36	0	25	0	8400	6700	Max. Trac.	" "
" "	36	0	25	0	12400	6700	" "	" "
" "	37	0	28	0	10350	6700	" "	City service
Pullman Co.	38	0	28	5	15670	10600	Double	Suburban
Brill Co.	40	0	29	0	13460	10200	"	"
" "	42	0	32	0	16740	11080	"	Interurban
Kuhlman Co.	42	2	32	0	14000	10600	"	"
Pullman Co.	43	0	32	6	17130	10400	"	"
Manhattan Co.	45	11	39	5	20000	10000	"	Trailer
Wason Co.	47	0	39	6	22350	10200	"	Brooklyn Trailer El.
St. Louis Co.	48	3	36	0	20000	13000	"	Interurban
Manhattan Co.	50	10	42	0	22000	15000	"	Elevated Ry.
Brill Co.	51	0	43	0	30500	13500	"	Wilkesbarre Hazelton
	52	10	44	0	56300	21000	"	Interboro Steel Body
	60	0	50	0	85100	21000	"	N. Y. C. Steel Body

ELECTRIC LOCOMOTIVES.

309. The **first use** to which electric locomotives were put arose from the necessity of taking care of miscellaneous freight work on interurban and suburban lines, and Fig. 73 represents a typical locomotive for this class of service operating for several years upon the St. Louis & Belleville Railway.

310. As this locomotive is typical of the earlier type of **small electric** locomotive, some of its **general data** are given as follows:

Total weight	100,000 pounds
Weight on drivers	100,000 "
Weight per axle	25,000 "
Weight of motors, control, etc.	30,000 "
Weight of trucks, superstructure, etc.	70,000 "
Rigid wheel base	6 ft.
Total wheel base	20 ft. 6 in.

* *Above weights* do not include weight of motor and control equipment.

Diameter of drivers........................33 in.
Number of motors..........................4
Type of motors...........................GE-55 Two-turn armature
Nominal rating of locomotive...............360 hp.
Type of motors............................d.c. 600 volts

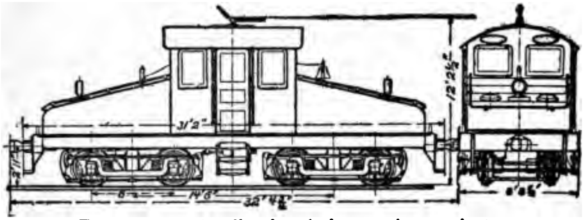


Fig. 73.—100,000-lb. electric locomotive, early type.

This type of locomotive is well adapted for the miscellaneous haulage work incident to the operation of suburban lines.

311. A more **modern type of locomotive** having end instead of side

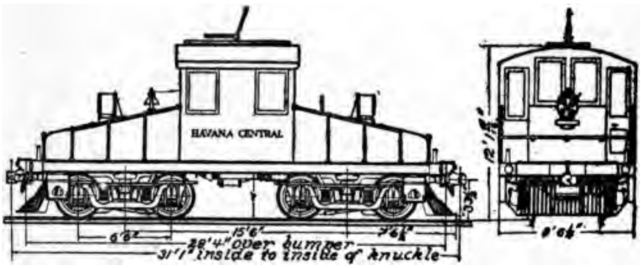


Fig. 74.—80,000-lb. electric locomotive.

doors and a better arrangement of the superstructure is illustrated in Fig. 74, this locomotive having the same equipment as that given for the St. Louis & Belleville.

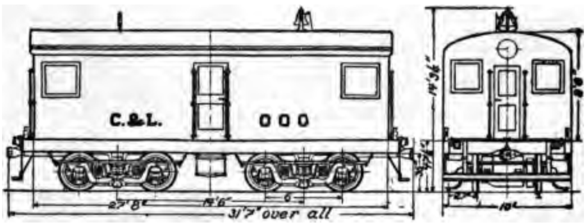


Fig. 75.—110,000-lb. electric locomotive.

312. In some cases it is desirable to utilize the superstructure of the **locomotive** to **carrying miscellaneous freight and express matter**, and such a type of locomotive is indicated in Fig. 75, where the superstructure is constructed with this end in view.

One of the earlier installations of electric locomotives of large size was that of the B. & O. terminal at Baltimore, the electric locomotive being adopted in place of steam in order to overcome the smoke nuisance in the tunnel. The first electric locomotives were equipped with gearless motors and are still in operation.

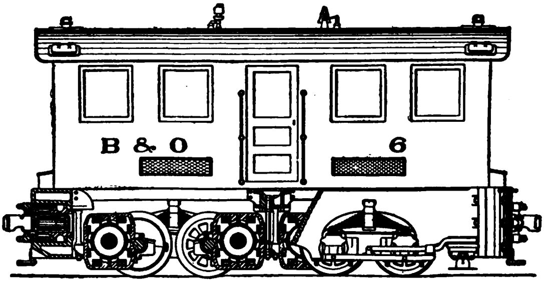


Fig. 76.—160,000-lb. electric locomotive.

313. A later installation was made with geared motors, the type of locomotive being indicated in Fig. 76. The following data apply:

Total weight of locomotive (two units).........	320,000 lb.
Number of motors..........................	8
Capacity of locomotive (two units)............	1600 hp.
Type of motor................................	Four-pole, d.c. geared
Diameter of drivers...........................	42 in.
Rigid wheel base..............................	14 ft. 6¾ in.

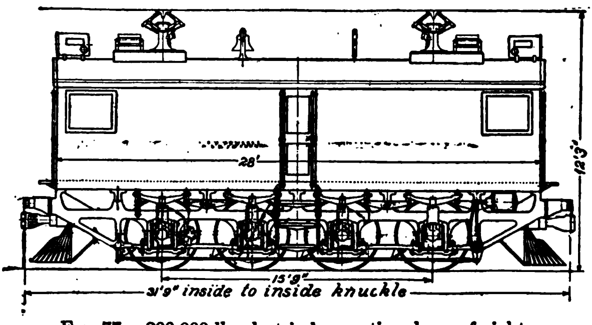


Fig. 77.—200,000-lb. electric locomotive, heavy freight.

314. In Fig. 76 the single unit as shown weighs 80 tons, all weight being upon the drivers, and the complete locomotive consists of two such units coupled together. As this type of locomotive is equipped with multiple-unit control, the two units composing the complete locomotive can be operated by a single operator in the leading cab. Owing to the rigid wheel-base construction and the low center of gravity of this type of locomotive, its use is restricted to operation upon track having curves *of large radius* and in a service calling for low-speed operation.

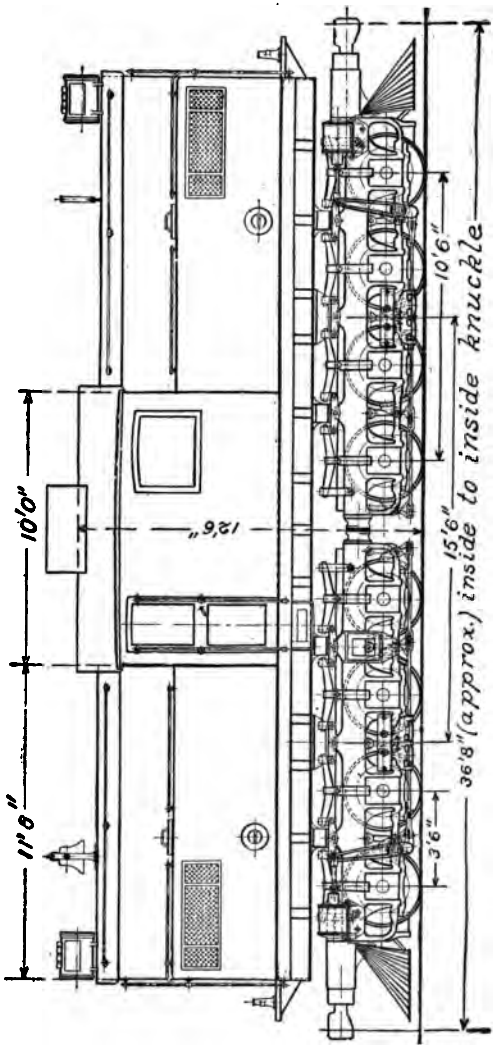


FIG. 78.—200,000-lb. electric locomotive, heavy freight.

315. Another type of **locomotive** suitable **for heavy freight haulage** at low speed is indicated in Fig. 77, which shows a locomotive having a rigid wheel base of 15 feet 9 inches, all weight upon the drivers, and having a 200 hp. motor geared to each axle. This locomotive may be used singly, or coupled with other locomotives and operated in a group by a single motorman, by the use of the multiple-unit control system. The type of locomotive shown is equipped with d.c. geared motors and arranged for operation with both third rail and overhead third rail, but the construction is equally adaptable for use with geared a.c. single-phase motors operated in connection with overhead high potential trolley.

316. It is sometimes desirable to concentrate the entire **motive power** required **in a single construction** instead of using a locomotive composed of two separate independent units. Fig. 78 represents a type of locomotive comprising two eight-wheel bogie trucks upon which are mounted eight motors of 250 hp. each. This type of locomotive is particularly adapted to operation over tracks having no sharp curves and on a service that does not call for speeds exceeding 40 to 50 miles per hr. maximum. It offers little flexibility either in design or in operation, and is especially adapted to a gearless motor construction in order to keep the rigid wheel base within reasonable limits.

317. Instead of concentrating the total motive power in a single structure there are many good reasons advanced for a construction similar to Fig. 79, which is designed to operate either as a single unit as shown or

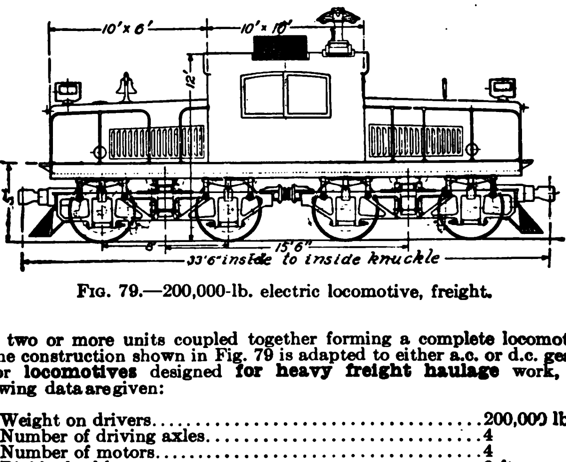


FIG. 79.—200,000-lb. electric locomotive, freight.

with two or more units coupled together forming a complete locomotive. As the construction shown in Fig. 79 is adapted to either a.c. or d.c. geared motor **locomotives** designed **for heavy freight haulage** work, the following data are given:

Weight on drivers	200,000 lb.
Number of driving axles	4
Number of motors	4
Rigid wheel base	8 ft.
Total wheel base	23 ft. 6 in.
Capacity total	1200 hp.
Diameter of drivers	48 in.
Maximum tractive effort at 22 per cent	44,000 lb.

318. The locomotive shown in Fig. 79 is for use with d.c. motors using forced ventilation, the intake being through the grid shown in the top of the cab. The design, however, lends itself equally well to the use of a.c. motors of the geared type, and locomotives of this type can operate with equal satisfaction in moderate speed passenger service where the maximum speed does not greatly exceed 60 miles per hr. The bogie truck construction is especially adapted to locomotive operation around sharp curves or at high speeds on tangents, hence the type in Fig. 79 is universal in its *characteristics.*

319. All the above locomotives shown are more especially adapted to freight haulage at moderate speeds. The electrification of the New York Central Terminal and the approaching electrification of other steam railroad terminals has led to the adoption of electric locomotives suitable for the haulage of **passenger trains at high speed.**

320. In Fig. 80 there is indicated a side view of the **New York Central type of locomotive** which is unique, due to the fact that motors of the gearless type were adopted in this construction. The construction consists of four gearless motors having the armature mounted directly upon the

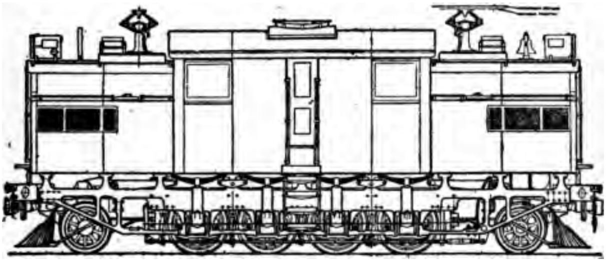


FIG. 80.—200,000-lb. electric locomotive (dimensions, see Fig. 7).

driving axle without the intervention of springs or flexible supports of any kind, and the mechanical structure of these four motors forming part of the locomotive frame (Fig. 81). The flux generated by the field coils traverses all four motors in series, returning partly by the overhead path indicated and partly through the field frame. The gearless motor was adopted in order to reduce the electric motor and its component parts to the greatest degree of simplicity in order to facilitate repairs, long life, etc. The four driving axles carrying the armatures of the four driving motors constitute the rigid wheel base of the locomotive, and there is added at either end a

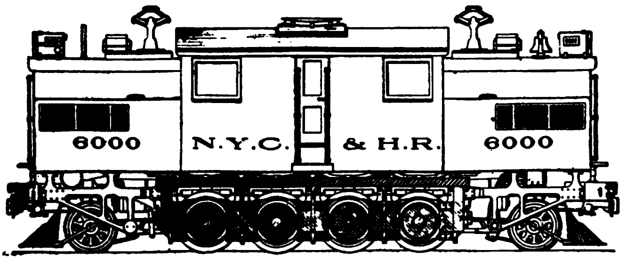


FIG. 81.—Section through frame of N. Y. C. locomotive,

pony truck to facilitate the rounding of curves and make the locomotive better adapted for high speed operation.

321. In Fig. 80 all limiting **dimensions** of a locomotive are given, **and** the following **data** apply:

Total weight of locomotive	200,000 lb.
Weight on drivers	140,000 "
Weight on guiding trucks	60,000 "
Weight of motors and electrical equipment	60,000 "
Weight of mechanical equipment	140,000 "

Diameter of driving wheels	44 in.
Diameter of pony wheels	36 in.
Rigid wheel base	13 ft.
Total wheel base	27 ft.
Total capacity	2200 hp.
Number of driving motors	4
Type of motors	d.c. gearless
Line potential	650 volts

322. The New York Central Locomotive is designed for **maximum speed** of approximately 60 miles per hr., and where extreme high speeds are required the type of locomotive shown in Fig. 83 is desirable.

323. This type of **high speed locomotive** comprises two four-axle bogie trucks, each truck consisting of two 44 inch driving axles and two 33 inch leading axles running light. The driving axles are equipped with d.c. gearless motors of a type similar to that on the New York Central locomotive, so that the capacity of the locomotive is practically the same as that of the New York Central type.

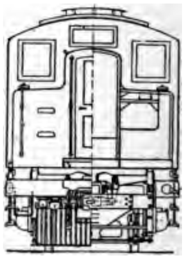


Fig. 82.

As the type of locomotive indicated in Fig. 83 represents the trend of **locomotive** design **for** very **high speed work,** the following **data** are given:

Total weight of locomotive	220,000 lb.
Weight on drivers	160,000 "
Weight of motors and electrical equipment	62,000 "
Weight of mechanical equipment	148,000 "
Ballast	10,000 "
Diameter of driving wheels	44 in.
Number of driving axles	4
Number of motors	4
Total capacity	2400 hp.
Type of motor	d.c. gearless

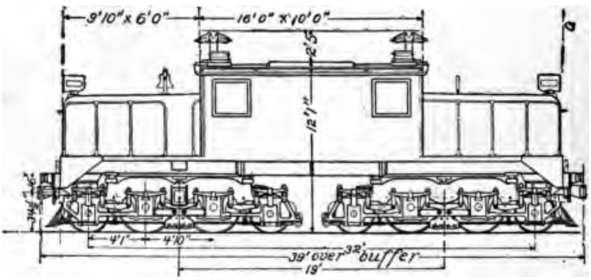


Fig. 83.—110-ton locomotive, high speed.

324. The single-phase motor has been adopted upon certain suburban lines operating with trolley potentials of from 3000 to 11,000 volts. The commercial operation of such roads demands the introduction of a locomotive equipped with a.c. motors. Although the a.c. single-phase motor is especially adapted for higher speed service it can be modified in design so that its characteristics are very satisfactory for locomotive operation at the lower speeds. **Industrial locomotives** are necessarily of the d.c. type, owing to the advantage of low voltage d.c. distribution in terminal *yards. For miscellaneous* freight haulage upon suburban and interurban

lines, the type of locomotive indicated in Fig. 74 is equally adaptable to d.c. or a.c. motor design, and such locomotives are now placed in operation upon several interurban systems equipped with high potential a.c. trolley.

There are two notable installations now in process of construction which utilize a.c. locomotives of unusual construction which are worthy of special mention.

325. The Sarnia tunnel forming part of the Grand Trunk Railway System is being electrically equipped, the service consisting in hauling a 1000-ton train through the tunnel in 15 minutes, a distance of 19,000 feet including approaches. Maximum grade in the tunnel is two per cent. The a.c. single-phase motor locomotive conforms to the following description:

Total weight of locomotive (two units).......	124 tons
Type....................................	Rigid wheel base three-axle
Length rigid wheel base....................	12 ft.
Diameter of driving wheels..................	62 in.
Number of motors per unit...	3
Power per motor one hour basis.......	250 hp.
Frequency................................	25 cycles
Type of motor...	Westinghouse single-phase compensated, geared type
Trolley voltage............................	3000
Motor voltage.............................	240

The motors are suspended on the axle in the usual standard method, that is, one end of the motor frame being hinged upon the axle and spring suspended from the truck at the other end.

326. The New York, New Haven & Hartford Company is installing electric **locomotives** to operate their New York Terminal. The system adopted is the single-phase motor system operating at 25 cycles from overhead 11,000 volt trolley, and the locomotives are unique both in the type of motor and method of suspension adopted. The locomotive comprises a superstructure resting upon two two-axle bogie trucks. Each axle is equipped with a gearless motor of the single-phase compensated type, the motor armature not being mounted directly on the axle as in the case of the New York Central d.c. motor construction, but mounted upon a quill surrounding the driving axle and spring supported there from with about five-eighths inch clearance, torque being delivered from armature to driving wheels through seven projecting pins engaging the driving wheel spokes through intermediate coil springs in the spoke sockets.

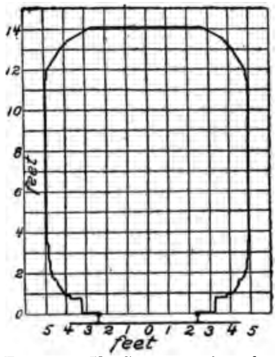


FIG. 84.—U. S. composite clearance limit.

The following data apply to this type of locomotive:

Total weight..............................	190,000 pounds
All weight on the drivers.	
Diameter of driving wheels...............	62 in.
Number of driving wheels................	8
Rigid wheel base........................	8 ft.
Number of motors.......................	4
Type of motor..........................	a.c. compensated, gearless
One-hour rating each motor..............	250 hp.
Operating voltage locomotive............	11,000
Operating voltage per motor.............	225

327. Both the step-down **transformers** and the motors themselves are **cooled** by forced ventilation. The duty of the locomotive consists in the

hauling of a 200-ton trailing load making a schedule speed of 26 miles per hour with stops two miles apart and a maximum speed of 45 miles per hour on tangent level track. The system is being installed by the Westinghouse Company.

328. The three-phase induction motor has been proposed and in one or two cases adopted as the type of motor for certain classes of locomotive service. There are no such installations as yet in the United States, but the strong claims of this type of motor for certain classes of service make it probable that such installations will be made in the near future, especially in mountain grade haulage service.

329. The motor-generator locomotive has been constructed and tested experimentally and offers many advantages for certain classes of work. It comprises briefly, a superstructure containing an induction motor generator set of either single-phase or three-phase type, furnishing direct current at 600 volts for the operation of standard d.c. motors of the geared or gearless type, mounted on the axle trucks. The claims for the motor-generator set rest on the fact that it makes available all the advantages of the standard d.c. motor combined with the advantages of high potential transmission over a single trolley wire. This type of locomotive is especially adapted for a service extending over lines equipped partly with a.c. trolley and partly with d.c. third rail, as on the d.c. sections the motor generator set is cut out and the locomotive operates with the d.c. motors fed from the third rail in the standard manner. Owing to the restrictions of weight and allowable space imposed it is possible to design motor generator sets of a limited capacity only, and the range of motor generator locomotives appears to be limited within 1000 kw. continuous capacity and double this capacity for short periods while starting. This output applies to a single unit, and it is possible to couple several units together with multiple-unit control as is done with other types of locomotives.

DISTRIBUTING SYSTEMS.

330. Train diagrams represent in graphic form the movement of all trains over a given division during the twenty-four hours of operation. Such diagrams are usually plotted with distance as ordinates and elapsed time as abscissæ, and they are of the greatest value in determining the average and maximum sustained demands upon the distributing and generating systems.

331. The average train input for a given service is determined according to previously outlined methods so that a train diagram is useful as indicating the local demand upon any part of the distribution system during any

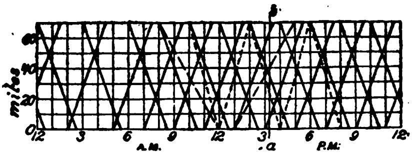


FIG. 85.—Typical train sheet (suburban service).

period of the twenty-four hours and also as giving the means of obtaining the total average load upon the entire division covered by the diagram, by plotting in curve form the total average kilowatts demanded by the several train movements intersecting equally spaced ordinates. Thus referring to Fig. 85, representing a typical train diagram wherein is depicted the performance of both local and express trains, the ordinate, $a-b$, intersects the line of five trains. Assume that the various trains demand the following average input:

Local passenger	100 kw.
Express passenger	130 "
Freight	210 "

The line, $a-b$, intersecting the various train movements, therefore, calls for a station output at 3:15 P.M. as follows:

Three local passenger trains	300 kw.
One express passenger train	130 "
One freight train	210 "
	640 kw.

332. By erecting other ordinates upon the twenty-four hour performance sheet it becomes possible by this means to plot a detailed generating station load curve for the twenty-four hours with the train movements as predetermined. This train load curve does not show momentary fluctuations and such fluctuations must also be considered in determining the character of the distribution system, especially in suburban and other systems where the train units are large and operate at infrequent intervals.

333. As affecting the distributing system, **railway service** may be divided into two broad **classes.**

1. Frequent or congested service.
2. Infrequent operation.

Under class 1 is grouped all city systems, underground or elevated roads and certain suburban roads where the headway between train units is small.

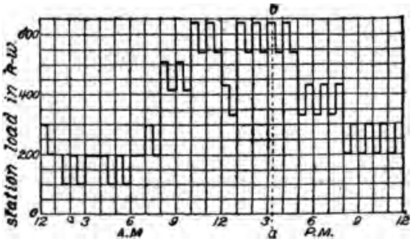


Fig. 86.—Typical load diagram.

334. Under class 2 is grouped all interurban and most suburban roads, in fact, all classes of service where the interval between trains is fairly large, as ten minutes or more, and where the train unit operates at a high maximum speed and thus demands a considerable input. The treatment of class 1 and 2 service as affecting the distribution system must be somewhat different as in class 1 momentary fluctuations due to starting of cars have little effect upon the size of conductor determined upon for feeders, or location and capacity of sub-stations if these are used. In class 2 the momentary input demanded during acceleration is often the determining factor in selecting the amount of feeder conductor and sub-station capacity required.

335. Distribution systems may be divided in general into two **classes.**

Secondary Systems.
Primary Systems.

Secondary systems consist of the trolley, third rail or other conducting medium, extending from the generating station or sub-station and the feeders connected thereto, and also the track return with its feeders and boosters, if used. The conductivity and physical characteristics of the secondary distributing system are determined partly by the momentary demand of each train unit and partly by the average input required by an aggregation of such units where the interval between trains is short.

336. For instance, in suburban service a high speed car may be equipped with motors aggregating 300 hp. to the car, and the conditions of service may demand an input during acceleration of 400 kw., while the average

input to the car including acceleration, coasting, braking and standing still during stops, may not be much greater than 100 kw. per car. As the train interval is so great that possibly not more than two cars receive power from a sub-station at one time, it becomes necessary carefully to determine the amount of overload during starting as influencing the conductivity of the distributing circuit and the sub-station capacity. On the other hand in city service, a sub-station or generating station may feed fifty or more cars and individual feeders may carry the load of perhaps fifteen cars, thus, making the momentary demand of any one car a matter of small importance. In such cases the determination of conductivity and sub-station capacity would rest upon the sum of the average load of all the cars.

337. The permissible **drop in voltage** of the conducting system between car and bus-bar with a specified load determines its conductivity. This permissible drop varies under different conditions of operation and types of apparatus used.

Permissible Drop (Approximate).

City systems................	8 per cent average	12 per cent maximum
Suburban d. c. systems......	10 " " "	20 " " "
Interurban d. c. systems.....	12 " " "	25 " " "
Interurban a c. systems......	5 " " "	10 " " "
Three-phase induction motor systems.................	5 " " "	10 " " "

338. The **conductivity of the circuit between motors and bus-bar** is seldom determined by a proper relation of interest on first cost of the conducting system and cost of energy lost, as the first cost of the distribution conductors so determined is considerably in excess of current practice in

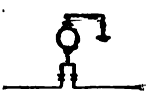


FIG. 87.—No feeders.

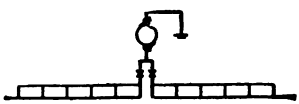


FIG. 88.—Single feeder.

this respect. In city systems the average and momentary maximum drop are practically the same owing to the small effect of the starting current of any one of the large number of cars controlled by one feeder. In interurban systems where generally but two cars are controlled by one feeder the maximum fluctuation is much in excess of the average drop.

339. Feeders are differently grouped according to the demands of the service and the physical arrangement of the trolley sections.

340. The **simplest conducting system** to the car upon the track consists in that shown in Fig. 87, wherein the trolley is connected direct through circuit-breakers to the positive bus-bar with no auxiliary feeders, and the negative bus is connected to the track return. The trolley is generally sectioned at the station and each section controlled by an independent feeder panel.

341. Where the trolley conductor itself has not a sufficiently low conductivity it is reinforced with **auxiliary feeders** connected to it at frequent intervals. The result of such feeder reinforcement is simply to increase the conductivity of the trolley circuit and is in effect the same as enlarging the cross-section of the trolley conductor itself. This grouping is best fitted for feeding a small number of units, and is more useful in the operation of suburban or interurban systems than in city work.

342. The **most economical** copper **distribution** for feeding a large number of train units would consist in a separate feeder to each train so proportioned that the drop in all feeders would be equal to the maximum drop permissible. As this would be impossible without too great a multiplicity of feeders, the arrangement in Fig. 88 is adopted which is the same thing in effect

343. A better arrangement of the same feeder connection is shown in *Fig. 90, which is identical* to that in Fig. 89, except that the trolley itself is

sectioned so that each feeder independently controls a single section of trolley and the cars drawing energy from that section.

344. Trolley sections may be from a few hundred yards to two miles or more in length in city service, depending upon the layout of the streets and the importance of so sectioning off different streets and different sections of the same street, so as to occassion the least possible interruption to general traffic in case of failure of any one trolley section or its feeder.

345. The trolley may be solid throughout as shown in Fig. 89, or preferably sectioned as shown in Fig. 90, in which case the different sections are entirely independent and each feeder and each trolley section is calculated to give the limiting I R drop when feeding the maximum group of cars drawing energy from that section of the trolley. The d. c. feeder distribution shown in Fig. 90, applies more especially to city systems and may be elaborated to any extent required by the complexity of a large city trolley system. Sectionalizing the trolley is desirable from the standpoint of localizing the effect of trolley breaks or grounds, and is necessary in large city systems supplying a large number of car units traveling over different routes. Thus with the sectionalized system the failure of the trolley on one section will not effect the operation of cars on a different route. The ends of trolley sections should be brought to a pole and connected to a switch or circuit breaker which may be closed if desirable, as in the case of possible failure of an individual trolley feeder. These trolley-pole switches may be operated manually or electrically from the supply station when located at very important points not convenient of access.

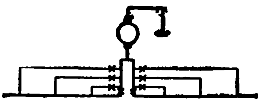


FIG. 89.—Multiple feeders.

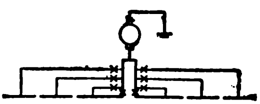


FIG. 90.—Sectioned trolley.

346. Calculations of conductor material required for d. c. distribution systems necessarily depend upon the voltage drop assumed for the class of service under consideration. The standard potential of d. c. generators has been raised from the original standard of 500 volts to the present accepted practice of 600 volts, flat compounding at the switchboard. A trolley potential of 600 volts is in almost universal use for suburban roads, but somewhat lower potentials are still used in many city systems where obsolete motor equipments having insufficient insulation or poor commutation, will not permit the use of higher potentials than 500 to 550 volts.

347. City service demands a **feeder distribution** capable of taking care of rush daily loads without prohibitive drop and also infrequent heavy loads on certain sections such as those due to amusement parks, race courses, etc. The rush daily load justifies the expense of feeder conductor permanently installed, but infrequent loads are best taken care of by feeders arranged for use with series or shunt boosters in the power house. In other words, the infrequent load occurs so seldom that it does not justify the expense of a large amount of feeder conductor, which may be inoperative during the greater portion of the year. With the pyramidal feeder system, Figs. 89 and 90, it is entirely possible to use the outside feeder as a booster feeder in case the heavy infrequent load should occasion a prohibitive drop.

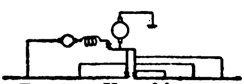


FIG. 91.—Use of booster.

348. A city feeder system should be so designed that the voltage of no part of the trolley to ground will be more than 100 volts lower than that at the switchboard when momentary fluctuations due to starting cars are eliminated. This 100 volt average drop should apply to the rush load occurring in daily operation. The **laying out** of a **city d. c. net work** consists in establishing the limits of the territory controlled by each sub-station (or generating station if separate stations be used), sectionalizing the district according to routes and streets, determining the average load upon each section as obtained from the average input demanded by the several cars on this section and determining the cross section of the conductor required

for return feeder sufficient to limit the I R drop including track return, to 100 volts. In crowded city districts the trolley will be cut up into such short sections that the additional I R drop occurring therein will not materially add to the combined return track and feeder drop of 100 volts. For the outlying districts a lesser drop of the feeder will be required in order to allow for the larger drop occurring in the longer trolley sections. Trolley sections will vary in length depending upon the density of service, street intersections, etc., ranging from one quarter of a mile up to two miles or more in the suburbs.

349. City distribution systems thus consist of the following:

1. **A trolley** consisting of a grooved copper conductor upheld by so-called cross suspension approximately 20 feet to 22 feet over the center of the track. This trolley conductor is sectionalized according to local requirements into lengths of from one quarter of a mile to two miles or more.

2. **A feeder system** consisting of copper conductors extending from the several trolley sections to the supply station. The feeders may be underground in conduits in the congested sections and carried overhead on poles in the suburbs, or in small towns.

3. **A booster** in the supply station which can be connected in series with any feeder extending to a temporarily overloaded section for the purpose of supplying the added voltage required to compensate for the excessive feeder and trolley drop.

4. **A track return** consisting of the track rails bonded at the joints.

5. **Track return feeders** consisting of copper conductors reinforcing the track at points of greatest drop or at points where the track is negative to the neighboring pipes.

6. **Pressure wires** extending to important points on both trolley, track and pipes, and serving to indicate at all times the potential of the several parts of the distribution system.

Such large city systems are a matter of growth and not of calculation, as the practice giving good results in one city may not be directly applicable to the different conditions obtaining in another city.

350. Conduit systems comprise a distribution system wherein the overhead trolley is replaced by a double conductor placed in a conduit located between the rails. The conductors comprise both positive and negative rails and hence there is no track return circuit, thus calling for double the number of feeders required with the sectionalized overhead trolley used with track return. As both positive and negative rails are insulated from ground the conduit systems practically eliminate any tendency to stray currents and electrolysis. Conduit systems are installed to avoid the unsightliness of the overhead trolley and can only be considered in the largest cities owing to the enormous expense of their installation.

351. Primary distribution comprises the location of sub-stations and the high tension transmission overhead lines or underground cables connecting them to the generating station bus-bar. Primary transmission systems invariably employ a. c. current, and where synchronous converters or motor-generator sets are used, this current is of the three-phase type transmitted over three wires or in multiples of three if duplicate circuits are provided for. Owing to the novelty of single-phase railway motor distribution systems and the close interconnection of secondary and primary distribution systems when applied to a. c. motor operation, this subject will be considered later under this same head of primary distribution systems.

352. Sub-stations for direct current systems are located at strategic points along the line of travel best suited for secondary distribution. These sub-stations may be fed from a common trunk line to which all sub-stations are connected, this being common practice in suburban and interurban railways operated by direct current motors. In such cases the trunk line preferably consists of two independent circuits, each of which may be used alone providing for continuity of service in case of accidental grounding of one set of lines. It is common practice also, to interrupt the transmission line at each sub-station, providing both incoming and outgoing line panels at each sub-station, so that the transmission line troubles may be localized between two adjacent subs rather than put a whole trunk line out of commission due to the fault of any portion thereof.

353. In city systems or in interurban systems where the traffic is very heavy and freedom from interruption of service of greatest importance, it is good practice to connect each sub-station to the generating station bus-bar through its own transmission line or underground cable. In fact, if the sub-station is very large this divisibility of the transmission circuit is sometimes carried to the extreme of providing each sub-station with several cables connected either to individual synchronous converters or to different bus-bar sections. each section controlling two or more synchronous converters. It is evident that this multiplicity of high tension transmission lines or cables can be made use of only in very large and important city or interurban systems taking care of a very congested traffic.

354. A. c. single-phase railway motor systems are best provided for by single-phase generation and transmission, owing to the simplicity of single-phase connections throughout the system. The method of connecting the various a. c. sub-stations to the generating station consists generally in tying all sub-stations to a single trunk line through circuit breakers designed to open on short circuit only. Individual transmission lines to each sub-station may be preferable under certain conditions, but multiplicity of transmission circuits is generally to be discouraged owing to the considerable increase in cost over a single or duplicate trunk line.

355. Owing to the enormous aggregate kilowatt capacity of three-phase 25-cycle generators already in operation for electric railway work and due to the fact that single-phase railway installations are often an extension of existing

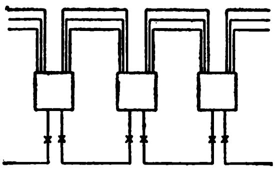


FIG. 92.—Sub-station system.

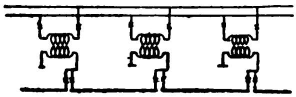


FIG. 93.—Straight 1-phase.

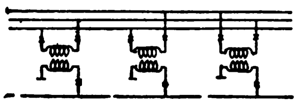


FIG. 94.—3-phase to 1-phase.

d.c. systems, it becomes necessary to consider the different systems of primary **distribution** for a.c. roads operating **from three-phase generators.** The simplest means is to use one leg of the three-phase system for the a.c. railway distribution, that is, treat the generator as a single-phase machine and carry out the transmission scheme and sub-station connections in all respects as though the other two legs of the three-phase generator did not exist. In this case the connections will be as described above for single-phase generators. The objection to this method of connections is the reduction of three-phase generator capacity resulting when operating single-phase. For the same heating the single-phase output of a three-phase generator will approximate two-thirds of its three-phase output on balanced load. Although single-phase distribution is simplest, the resulting reduction in generator capacity may be so serious in certain installations as to necessitate the consideration of three-phase distribution to the transformer sub-stations.

356. Where the road is of extended length, the secondary distribution or **trolley circuit** may be divided into sections and each section fed from a separate phase of the three-phase primary distribution system. This system of connections secures all the benefits of three-phase generation and transmission, provided the load is equally balanced upon the several trolley sections, but requires double the conductivity in the secondary distribution system owing to the impossibility of tving sub-stations solidly together so that trains midway between sub-stations will draw equally on both.

357. A modification of the three-phase single-phase sub-station connections is shown in Fig. 95, wherein each sub-station contains two

transformers connected in open delta so that corresponding phases feed each end of a trolley section and each succeeding trolley section will correspond to the different phases of the three-phase primary distribution. This method of connection is often open to the objection that the road is not of sufficient length to permit of dividing into a sufficient number of equally loaded sections to correspond to the three transmission phases or multiple thereof.

358. Three-phase two-phase transformer connection can be used where the road is of limited extent, and consists in employing the three-phase two-phase connection of sub-station transformer feeding the two-phases to adjacent trolley sections, so that corresponding phases will be fed to a given trolley section from the transformer sub-station at its terminals. This system of connections will not provide perfect balance upon the three-phase side of the transformers unless the loads are balanced upon the several trolley sections. Sufficient balancing, however, may be obtained in the majority of cases, and this system of connection is in quite extended use.

359. Two-phase generators may be used to supply single-phase railway distribution systems by sending out transmission lines from the two phases in different directions, thus amounting in principle to two separate single-phase transmission systems. This connection is open to the objection that unless the loads are perfectly balanced upon the two phases, the voltage regulation will be very poor and in cases of generators having poor inherent regulation, it may reach such proportions as to endanger the lamps and general operation of the equipments.

360. In general a new railway system favorable for the operation of a.c. motors operates to best advantage with the single-phase system of generation and transmission where the contemplated road has no future

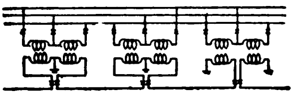


Fig. 95.—3-phase to 1-phase.

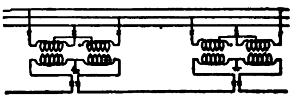


Fig. 96.—3-phase to 1-phase.

connections with neighboring systems and is free from entanglements, such as power distribution. operation of synchronous converters, etc., requiring multiphase generation and distribution. Where it is advisable to provide for the future utilization of three-phase power, three-phase generators may be installed, operating either on one leg as single-phase generators or using all three legs in connection with three-phase two-phase transformer connections in the sub-stations in order to provide for reasonably good balancing of the three-phase primary distribution.

361. Three-phase induction motor systems may employ the same method of sub-station connections and primary distribution as outlined under the head of synchronous converter sub-stations for d.c. motor systems. Owing to the fact, however, that transformer sub-stations of all kinds may be operated without attendance, such sub-stations are best connected to a main trunk line through circuit breakers operated by relays designed to open only on short circuit. Where the control of the sub-station is extremely important, attendance should be supplied or each individual sub-station should be connected to the generating station by separate transmission lines having automatic control at the generating end only. In all cases the trolley or secondary connection to the transformer sub-station should be safe guarded by automatic switches designed to open at short circuit.

362. Resistance of trolley circuits is dependent upon the weight of trolley copper and track rail, and also upon the composition and bonding of the latter. Trolley conductors are either 00, 000, or 0000 B. and S., the smallest size being seldom used owing to its lack of strength and the difficulty of clamping its small diameter.

363. Track rails contain as high as 0.40 to 0.50 per cent. carbon and 0.70 per cent. manganese, these two elements largely effecting the specific resistance, hence standard track rail may be taken at approximately 20 microhms

per centimeter cube* when bonded with bonds having half the conductivity of the rail.

364. Trolley and Track Resistance per Mile.

Track Rail	Ohms Resistance 2 rails	000 Trolley and 2 rails	0000 Trolley and 2 Rails
50 lb. per yd......	0.053	0.383	0.313
60 " " "	0.044	0.374	0.304
70 " " "	0.038	0.368	0.298
80 " " "	0.033	0.363	0.293
90 " " "	0.030	0.360	0.290
100 " " "	0.027	0.357	0.287
110 " " "	0.024	0.354	0.284

000 Trolley = 0.33 ohms. 0000 Trolley = 0.26 ohms.

365. The use of alternating current in the trolley and rail-circuit necessitates some modification in the above values as the resistance is increased by reason of the inductive reactance of both trolley and rail and due also to eddy currents set up in the rail itself.

366. The **impedance of a rail** depends in a considerable degree upon its chemical composition, a reduction in permeability also reducing the internal losses. In general the action is a skin effect and the impedance and resistance are inversely proportional to the perimeter of the rail and proportional to the square root of the frequency. This proportion assumes an unbroken rail and the introduction of short lengths of rail bonded together calls for modifications. Thus at 25 cycles the impedance of track rail of standard outline and composition is approximately eight times the ohmic resistance offered to the passage of d.c. current, and at 15 cycles a ratio of 6.2, etc. The power factor at either frequency is approximately 80 per cent. Considering a track circuit with bonding, experimental results show an impedance at 25 cycles of 6.6 times the resistance with d.c. current.

367. In addition to the increased impedance of the rail itself, the **impedance of the overhead trolley** conductor is also increased by reason of its reactance when carrying alternating current. Tests made upon a 000 and 0000 conductor indicate an increase in impedance of 1.5 the ohmic resistance with d.c. current.

368. Track Rail Impedance 25 Cycles (see 369).

Ratio a.c. to d.c. = 6.6 = 1

Weight of rail lb .per yd.	60	70	80	90	100	110
Impedance ohms per mile 2 rails	0.291	0.251	0.218	0.198	0.179	0.115

000 Trolley = .495 ohms. Ratio to d.c. 1.5
0000 Trolley = .390 ohms. " " " "

369. Table (368) is based upon the following constants:

Height of trolley above track approximately	20 ft.
Gauge of track standard	4 ft. 8½ in.
Power factor of circuit	80 per cent.
Average power factor of load	80 per cent.

370. The **height of trolley above rail** can be varied somewhat from the 20 ft. assumed without introducing an appreciable error. The power factor of 80 per cent. assumed for the load is somewhat lower than would be experienced in a well proportioned a.c. railway installation, but the small error of four or five per cent. introduced by assuming full impedance drop at

*A cube whose side = 1 cm.

the trolley and rail circuit is justifiable in making preliminary estimates where the character of load cannot be very closely determined.

371. Trolley construction may be divided into two broad classes:

1. Span Construction.
2. Bracket Construction.

372. Span construction comprises poles on either side of the track connected by cable from which is suspended the trolley conductor. The trolley may be hung directly from the span wire through an intermediary insulated hanger or may be suspended from a galvanized steel catenary which in turn is supported by the span wire. Span construction may be used to provide a support for the trolley wires over any number of tracks. With more than two tracks it is preferable that the side poles shall be self supporting steel

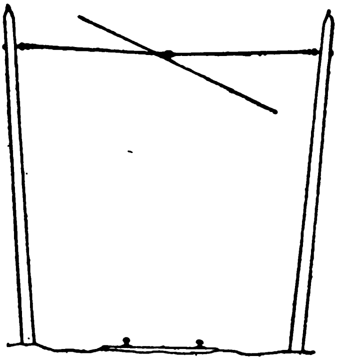


Fig. 97.—Cross suspension.

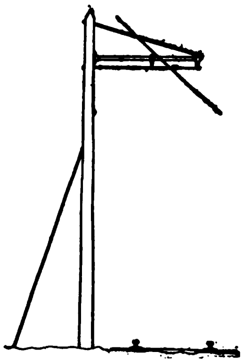


Fig. 98.—Bracket suspension.

towers joined by very heavy catenary construction, the whole combination being thoroughly anchored to withstand strains, or else the side towers should be joined by a light steel truss forming a bridge construction, this latter being used in steam-railroad electrification where the number of tracks exceeds two.

373. Trolley wires generally have a cross section equal to 3/0 or 4/0 B. and S. gauge, and are drawn in three sections:

Round, Figure 8. Grooved.

The use of the round wire is objectionable owing to the difficulty of securely clipping it to the hangers without forming a projection on the wire itself which will tend to throw the current collector off in high speed operation.

374. The use of **figure 8 wire** is open to the objection that owing to its unsymmetrical cross section it is very difficult to handle during installation, although it affords a ready means of fastening and leaves a clean unbroken undersurface suitable for high speed operation.

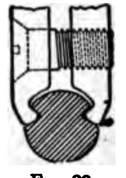


Fig. 99.

375. The **grooved trolley wire** is in greatest use and consists of a round wire grooved on opposite sides sufficiently deep to permit gripping by adjustable clamps or hangers. Owing to its round cross section it is readily unreeled and installed, and presents all the advantages of a smooth under surface.

376. Bracket construction comprises a self-supporting pole having a *protecting arm or bracket* extending over the track and supporting the

trolley wire either direct or by means of a steel catenary cable. The pole is generally of wood. and the best construction provides for anchoring each pole to guard against lateral strains due to wind and the unbalanced weight of the overhung trolley.

377. The trolley is not generally attached directly to the projecting arm or bracket, but to a flexible cable attached thereto, whose office is to provide for the needed amount of flexibility. Span construction is more flexible

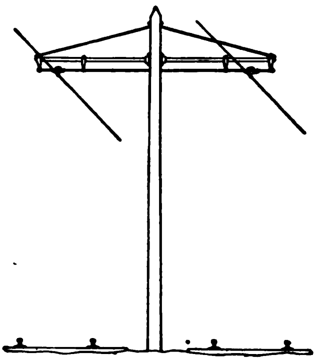


FIG. 100.—Two-track bracket construction.

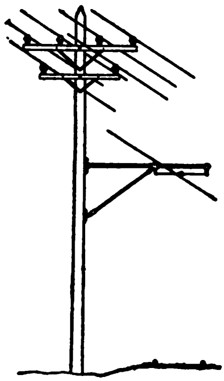


FIG. 101.—Combination pole.

than is bracket construction but by use of the flexible bracket cable, the latter can be made sufficiently cushioned to permit the operation of trolley wheels up to 60 miles per hour.

378. Catenary construction has been brought into prominence with the development of the a.c. motor but its application is not confined to a.c. motor installation as its excellent mechanical qualities are of equal benefit in the case of high speed d.c. motor installations. Catenary construction

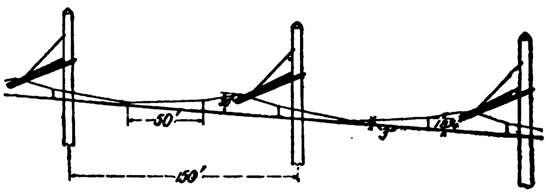


FIG. 102.—Three-point catenary suspension—tangent.

comprises either a span or bracket-supporting structure over which is hung a stranded galvanized steel cable loosely suspended with twenty inches or more drop between supports, thus giving rise to the term catenary. From this catenary or messenger cable is suspended the grooved trolley wire by means of hangers of different lengths, the number of these hangers varying from a minimum of three between supports to a maximum of a hanger every fourteen feet, the object being to secure a practically flat trolley wire of equal height at all points above the track.

379. The **flexible suspension of a catenary**-hung **trolley and the flat** surface which it presents to the trolley collector makes it admirably suited for the operation of high speed equipments whether these be of the a.c. or d.c. type. This form of construction is furthermore especially adapted to withstand the high voltage stress of the trolley voltages employed in a.c. secondary distribution systems, owing to the fact that the catenary is generally suspended from porcelain insulators of the high potential transmission type, forming both a strong mechanical structure and having high pressure resisting qualties.

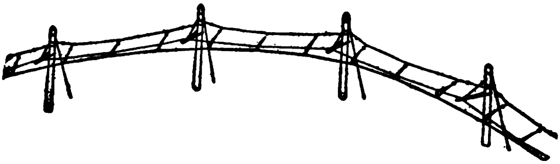


FIG. 103.—Three-point catenary suspension—curve.

380. With catenary construction it is possible to adopt a greater spacing between supports than is customary with the self supporting trolley wire construction.

381. Distance Between Supports on Tangents.

Self supporting trolley	110 ft.
Catenary wooden pole bracket construction	150 "
Catenary steel pole bracket construction	200 "
Catenary steel bridge construction	300 "

382. With wooden pole bracket construction it is customary to anchor the poles on curves, often on tangents. Primary transmission circuits may be carried upon the same poles that serve as a support for the trolley. The transmission line so supported may be supplemented by a separate transmission line hung on independent poles in order to provide greater assurance for continuity of service.

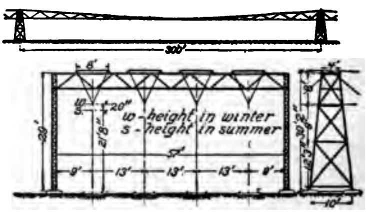


FIG. 104.—Catenary construction.

383. The only limit placed upon the **distance between supports** in catenary construction on tangent track is the liability of long spans to considerable lateral sway. This is corrected in part by suspending the trolley from a double catenary construction, thus forming a triangular truss of considerable rigidity. Catenary construction is only adapted to tangent track and curves of long radius, as it reauires additional pull-off poles and considerable expense in order to be adapted to sharp curves.

384. Standard trolley potentials in use:

600 Volts d.c.
1200 Volts d.c.
3300 Volts a.c.
6600 Volts a.c.
11000 Volts a.c.

The a.c. trolley potential of 3300 volts has been used in several installations but is being superseded by 6600 volts in the smaller, and 11,000 volts in the larger installations.

385. Collecting devices for use with overhead trolley may be divided into three classes:

Wheel, Roller, Sliding Bow.

386. The trolley wheel consists of a grooved wheel of composition metal ranging from 3.5 inches to 6 inches in diameter depending upon whether the service is low or high speed. Wheels are carried on a self-lubricating bearing and press against the trolley at pressures from 15 to 40 lb. depending upon the maximum speed of the equipment, this pressure being maintained throughout a wide range in height of trolley wire in order to provide for reduction in standard height of 22 ft. made necessary when going beneath bridges, culverts, etc.

387. Approximate Life of Trolley Wheels.

City Service 25 miles per hr. maximum.............	11,000 miles
Suburban Service 35 miles per hr. maximum........	6,000 "
Interurban Service 50 miles per hr. maximum.......	3,500 "
High speed service 60 miles per hr. maximum.......	2,000 "

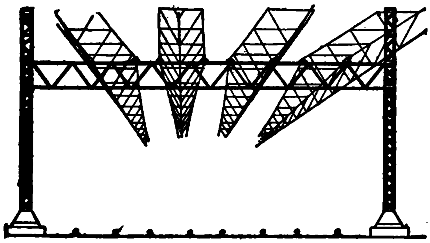


FIG. 105.—Double catenary construction.

388. The **current capacity of the trolley** is determined by its speed and the pressure of contact between wheel and wire, the higher the speed the greater the pressure necessary to maintain contact without arcing. High speed also demands a very nicely balanced wheel and the maximum speed at which trolley wheels are used correspond to a car speed of 60 miles per hr

389. Current Capacity of Wheels (see 390).

Speed in Miles per hr.	5	10	20	30	40	50	60
Current Capacity in amperes.	1000	850	650	550	400	300	200

390. Table (389) is compiled on the basis of maximum current carrying capacity at the different speeds with trolley and wheel in good condition, with wheel balanced for the higher speeds and with pressure varying from 20 to 40 lb. between trolley and trolley wheels.

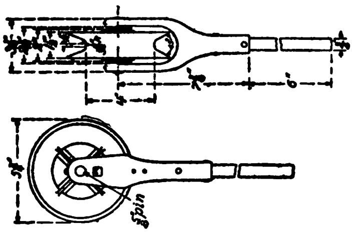


FIG. 106.—No. 12 fork; No 17 wheel.

391. At the **higher speeds** it is absolutely necessary that the **trolley suspension** be very flexible, preferably hung from a catenary and with the clip fastening the trolley wire of as light weight as possible in order to minimize the blow of the trolley wheel striking it.

392. Rollers are sometimes used in place of trolley wheels where it is desired to make use of a reversible collecting construction or where the trolley potential is so high as to make it desirable that all control of the

trolley collecting devices shall be automatic and not manual with cord. Rolling contacts consist of a brass or composition roller about 4 inches in diameter and 2 feet long supplemented by stationary wings to provide for greater off-center displacement of the trolley than can be taken care of by the 2-foot roller. Such construction is necessarily very heavy and is only adapted to low speed operation with standard trolley construction. When used for high-speed service it requires a very flexible suspension of the trolley in order that the inertia of the roller will not wreck the trolley support.

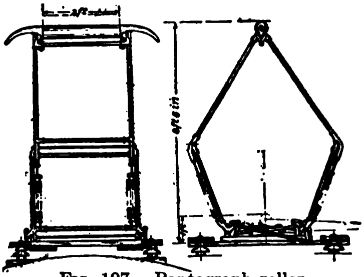


Fig. 107.—Pantograph roller.

393. Roller trolleys are in only partial use and there are no exact data as to their current capacity or life. It is probable that the carrying capacity is somewhat less than that given above for wheels and the life somewhat greater owing to the increased wearing surface presented.

394. Sliding bow trolleys are in very general use at moderate speeds, carrying currents of moderate value, and the development of high potential a.c. trolley collectors has brought this form of construction into prominence. In many a.c. roads the use of trolley wheels operated by means of insulated linen cord is still adhered to, but the majority of such roads are adopting some form of roller or sliding-bow contact. As the application of the sliding-bow trolley to high speed operation calls for certain modifications in its construction as hitherto made, no complete operating data are extant in regard to its carrying capacity or its life. For speeds between 50 and 60 miles per hr., the sliding contact has an appreciably less life than either the trolley wheel or roller, but continued use of the sliding bow at these speeds is resulting in the selection of metals and forms of construction which will provide for a reasonably long life.

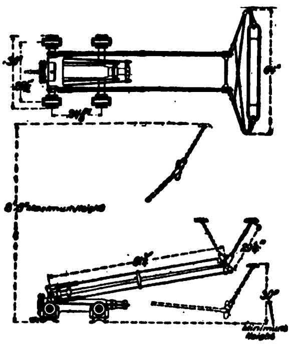


Fig. 108.—Sliding bow.

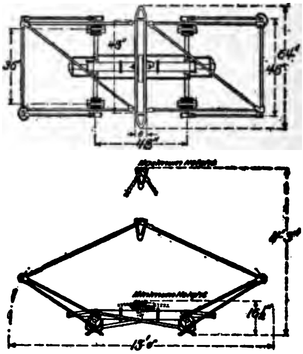


Fig. 109.—Pantograph bow.

395. Sliding-bow construction may be supported either by a trolley pole mounted upon a spring base along the lines of standard trolley wheel construction, or the bow or scraper may be held in a horizontal position at all heights by means of the so-called pantograph construction. The panto-

graph bow is preferable for a.c. roads as it permits reversal of the car direction without reversing the trolley, and furthermore, by reason of the parallel motion introduced, it does not interfere with trolley construction.

396. Third-rail construction may be divided into two broad classes:

1. Overrunning Contact. 2. Underrunning Contact.

397. Overrunning contact third rails were the first introduced and are in more general use. The construction consists essentially in supporting a steel rail of either standard track or special composition upon insulators placed every ten feet. These insulators rest on supports carried upon projecting ties. Rails are joined loosely by fish plates and are bonded and at intervals are thoroughly anchored to prevent creepage. Contact is made with the collecting surface of the rail by means of a third-rail shoe suspended from the trucks of the car or locomotive.

FIG. 110.—Third rail, unprotected.

398. Protected third-rail construction is a modification of the above and consists in providing a wooden or metal shield over the rail in order to protect it from snow and sleet or accidental contact, the rest of the construction being identical with that outlined above.

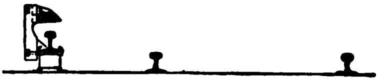


FIG. 111.—Third rail, protected.

399. Data Regarding Location of Third Rail on Different Electric Railways.

Name of Road	Above Track Rail, Inches	Gauge Line to Center Line of Rail, Inches
Albany and Hudson	6.0	27.0
Aurora, Elgin and Chicago	6.50	20.12
Baltimore and Ohio	3.5	30.0
Berlin Elevated and Underground	7.05	14.375
Boston Elevated	6.0	22.0
Brooklyn Elevated	6.00	22.00
Central London	1.50	At Center
Columbus, Buckeye Lake and Newark	6.0	27.0
Columbus, London and Springfield	6.0	27.0
Interborough Rapid Transit	4.0	26.0
Kings County Elevated, Brooklyn	5.25	19.50
Lackawanna and Wyoming Valley	6.0	20.37
Lake Street Elevated, Chicago	6.50	20.12
Liverpool Overhead Railway	1.50	at center
Long Island Railway	3.50	27.5
Manhattan Elevated (Fig. 110)	7.75	20.75
Mersey Railway	4.50	22.0
Metropolitan and District	3.00	16.00
Metropolitan West Side, Chicago	1.50 6.50	at center 20.12
Milan Gallarate	7.5	26.625
New York Central (Fig. 112)	2.75	28.25
Northeastern	3.25	19.25
North Western Elevated, Chicago	6.50	20.12
Paris-Orleans	7.125	25.625
Philadelphia and Western	3.625	27.00
Philadelphia Rapid Transit	3.625	27.00
South Side Elevated, Chicago	6.50	20.12
Waterloo and City	same level	28.25
West Jersey and Seashore	3.50	27.5
West Shore Railroad	2.75	32.0
Wilkesbarre and Hazelton (Fig. 111)	5.0	28.0

400. The location of the third rail is determined by physical characteristics of the rail and by the character of the rolling stock passing over it, that is, sufficient clearance must be provided to allow the passage of low pressure locomotive cylinders, hopper cars, etc., and also the third rail must be laid to provide sufficient clearance through tunnels, etc. The distance from track gauge line to center of third rail varies from 20 inches to 28 inches and the heighth above track is from zero inches to nearly 8 inches. The smaller distances apply to elevated and subway roads operating only one class of rolling stock, and the greater distances apply to interurban lines or electrified steam lines where provision must be made for the passage of all classes of freight cars and possible steam locomotives.

401. Jumpers are used to connect the third rail severed at crossings and consist of copper cables bonded to the rail and extending through underground conduits. Jumper cables are heavily insulated, are lead covered and enter the ground through solidly constructed concrete structures.

402. Insulators consist either of impregnated wooden blocks, reconstructed granite or porcelain, designed to be held in chairs fastened to elongated ties and forming a loose support for the third rail. In order to provide for elongation of third rail caused by extremes in temperature there is no solid fastening between the third rail and its insulating support, and jumpers must be of sufficient length to allow for creepage.

403. Protected rail construction provides for either wood or channel iron covering placed sufficiently above the rail to allow passage of the third rail shoe. The wood or iron protection is supported by uprights placed every ten feet or more, and such protection is usually substantial enough to bear the weight of a man midway between supports.

404. Underrunning third rails of the protected type, first installed on the New York Central R.R., offer some advantage over the overrunning type in regard to better protection against accidental contact and against sleet and snow. The contact surface being the under side, is self cleaning and this form of third rail has successfully operated through heavy snows completely covering the third rail structure.

FIG. 112.—Third rail, underrunning.

405. Leakage from third rail is extremely small and may be neglected unless the road bed should be deeply impregnated with salt. Even though the third rail be covered with snow it is found that the leakage is too small to constitute a noticable item of expense.

406. Bonding of the third rail is treated under track bonding (see **427**).

407. Third-rail shoes are of two general types, those acquiring their pressure by gravity and those actuated by means of springs. The unprotected overrunning third rail was first used in conjunction with gravity shoes and in many installations this form of shoe is still in operation. Where rails are protected it is necessary to provide a form of shoe which will operate in the limited space between rail and protection, and such shoes are hinged and actuated by springs in order to provide the necessary pressure.

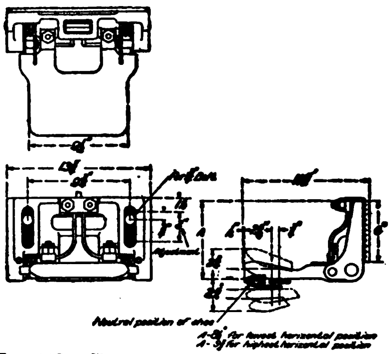


FIG. 113.—Shoe for standard and inverted rail.

408. Current capacity of third-rail shoes is much in excess of that of any form of overhead current collector, especially in regard to current capacity at high speeds. Tests have been made which indicate that electricity may be collected at the rate of 2000 amperes from a single shoe at a speed of 35 miles per hr., and 500 amperes at a speed of 70 miles per hr.

Owing to the considerable wearing surface of a cast iron shoe its life may be taken as exceeding 25,000 miles.

409. Conductivity of the third rail depends upon its composition, and it is sometimes the practice to roll third rails of special composition in order to increase their conductivity. The specific resistance of steel has been found to be proportional to the per cent of manganese and carbon which it contains. Of these two elements manganese is the most objectionable, and the standard track rail contains from 0.40 to 0.50 per cent carbon and as high as 0.70 manganese which gives it a specific resistance ranging from ten to twelve times that of pure copper. As samples of special composition third rails the Table (410) is given containing data from three installations in the United States.

410. Composition of Special Third Rails.

Material	Manhattan Railway	New York Subway	Albany and Hudson
Carbon	0.073	0.10	0.090
Manganese	0.340	0.60	0.440
Sulphur	0.073	0.05	0.08
Phosphorus	0.069	0.10	0.088
Ratio of resistance compared to copper	07.7	8.0	7.25

411. Suggested Third-Rail Composition.

Carbon not to exceed	0.12	per cent.
Manganese not to exceed	0.40	"
Sulphur not to exceed	0.05	"
Phosphorus not to exceed	0.10	"

412. The specific resistance of a third rail of composition given in Table (411) will be approximately 14 michroms per centimeter cube* at 20 degrees C, or seven and three-quarters times that of commercial copper.

413. Including bonds, Table (414) is compiled as being representative of third rail rolled according to specifications in Table (411) for special rail giving 14 microhms per centimeter cube and for a track rail a composition giving 20 microhms per centimeter cube.*

414. Resistance of Rails Including Bonds (see 413 and 415).

Weight of rail lb. per yd.	40	50	60	70	80	90	100	110
Third rail resistance ohms per mile	0.093	0.074	0.062	0.053	0.046	0.042	0.038	0.034
Two track rails resistance ohms per mile	0.066	0.053	0.044	0.038	0.033	0.033	0.027	0.024

415. Table (414) is based upon the use of 9 inch bonds having a carrying capacity equal to one-half that of the rail.

416. Third-rail maintenance is a very small rtem as tests have shown the rail to wear an extremely small amount, even in very heavy service. Tests taken show that the passage of 2,000,000 third rail shoes resulted in wearing away 0.006 inches of special soft rail. The maintenance of a third rail includes such items of expense as maintaining the bonding, alignment, and insulators in good condition together with the upkeep of jumpers and the cables. This expense has been found in practice to be very small and

*Meaning cube whose side = 1 cm.

the low maintenance charge of third rails together with the possibility which such a system offers for handling unlimited current values at any speed constitute the strongest arguments in favor of its adoption.

417. Protection against sleet and snow is affected directly by the various forms of protected third rail, and it has been found that especially the underrunning type can operate in snow entirely surrounding the third rail without difficulty owing to the fact that the under contact surface of the rail is selfcleaning.

With the various forms of exposed overrunning rail it has been found that the accummulation of sleet may be prevented by the use of calcium chloride mixed with water in the proportion of one pound to five gallons and sprayed upon the rail at intervals of not more than two hours during the continuance of the storm.

418. Conduit systems are in use only in the very largest cities owing to the enormous expense of their installation. Such systems consist in the location of two third rails or conductors placed in a conduit located between the track rails, contact being established by means of a plough extending through a slot opening of the conduit. As the plough carries both the positive and negative contacts there is no track return and hence the conductivity of the track as return feeder is lost.

419. Conduit systems are installed **in city streets** where the congestion of travel is sufficiently heavy to warrant the large expense and where the use of overhead wires is objectionable. As conduit systems are essentially double trolley systems, the feeder net work is double that required for an overhead trolley with track return. Both conductor rails are controlled by separate feeders, are divided into sections as previously indicated for city trolley systems, and each section with its feeders is controlled by double-throw switches so that it may be made either positive or negative at will. With this arrangement of double throw switches it becomes possibe to throw all temporary grounded sections on the same polarity bus and thus prevent possible short circuits due to simultaneous grounding of a positive and a negative conduit conductor.

420. Double-trolley systems are installed to a limited extent in city streets in order to prevent any liability to electrolysis possible with the single-trolley track return system. Such systems call for double collectors and double-trolley construction which becomes complicated and expensive to maintain in city streets. One trolley is positive the other negative, so that the track is not utilized for return and hence does not have to be bonded.

421. Double-trolley systems or double third rail systems are sometimes used in conjunction **with three-phase** induction motor equipments requiring three conductors in which case the track acts as the third leg of the triangle. Such systems usually employ several thousand volts upon the trolley wires, employ the catenary overhead construction, and are as yet in very limited use.

422. Three-wire systems comprise two overhead trolleys having a difference of 1200 volts between them and 600 volts each to ground. In this case the car equipment consists of two separate 600-volt motor equipments including control, connection being established with the track as a neutral. Such systems can therefore operate either as 600-volt from either or both trolleys, or as a straight 1200 volt system trolley-to-trolley with the track acting as a neutral and carrying practically no current. Where there is no restriction placed upon the voltage drop in track return such systems suffer in comparative first cost with the single trolley system.

423. It is almost the universal custom in electric railway systems to utilize one or both rails of the **tracks as a return circuit** to the generating station. It was early found that the ground itself or even adjacent bodies of water constituted a return circuit of such high resistance as to be of little practical use, and hence the necessity for a carefully bonded track return circuit reinforced by feeders where necessary.

The **conductivity of track** is given under third rails. (See **414**).

424. Electrolysis. Although the track is partially insulated from the ground by wooden ties it is found that in city streets there is a tendency for considerable leakage to neighboring pipes giving rise in some extreme *cases to* very rapid deterioration. The causes underlying electrolysis, at

first very imperfectly understood, appear to be that apparently pipe lines in some cases act as a path of lower resistance than the track itself, causing a tendency of the electricity to flow from the track to the pipes. When the pipe is negative to the rail, that is, when electricity enters the pipe, there is no tendency to electrolysis, but at certain points where the track becomes a better conductor than the rail and the electricity flows again from pipe to rail, electrolysis will take place.

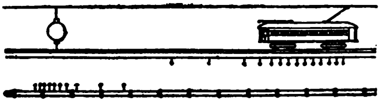


FIG. 114.—Stray current distribution.

425. To limit the liability to electrolysis, certain local regulations restrict the drop in the track-return circuit to seven volts maximum, thus calling for very heavy track return feeders and in some cases of the installation of track return boosters. Enforcement of this regulation may not necessarily entirely cure electrolysis trouble, and a better protection seems to be afforded by following out the method outlined herewith.

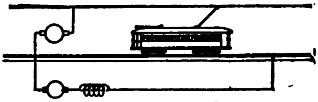


FIG. 115.—Negative booster.

426. Pressure wires should be run to neighboring pipes tapping them at frequent intervals and also tapping the track rails in the same locality. It is thus possible for a station attendant to read the voltage between track and pipes at any time during the day and throw in or out track feeders as demanded by the degree of variation and the polarity of the pipe in respect to the track. If the track is too good a conductor in certain localities it will cause electrolysis in the neighboring pipes, so that it is possible to install too good a track return and thus defeat the purpose for which the return feeders were installed. Instead of track feeders being connected direct to the negative bus, these may feed through series boosters in order to economize in return conductors.

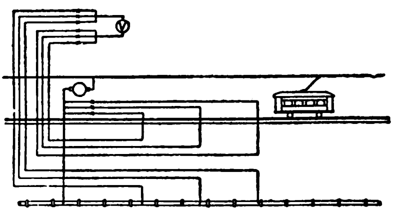


FIG. 116.—Track feeders and pilot wires.

427. Rail bonding consists in establishing contact, rail to rail, in order to utilize to the fullest extent the conductivity of the rail as a return circuit or as a third rail. The contact resistance of fish plates is so great as to amount to a practical open circuit, hence the need of a bonded joint of good conductivity.

428. The question of bonding has largely resolved itself into the mechanical problem of maintaining a low resistance contact that will withstand the constant pounding and extreme changes in temperature to which the joint is subjected under operating conditions.

429. Types of Bonds.

1. Expanded Terminal Bonds.	4. Cast Welding.
2. Soldered, Braized or Welded Bond.	5. Electric Welding.
3. Amalgam Bonds.	6. Thermite Process.

430. Expanded terminal bonds comprise all those which depend upon expanding a soft copper core into contact with the rail through a hole in the web or flange. The size of hole in the rail varies with the capacity and type of bond used, ranging from ⅝ of an inch to 1 inch in diameter. There are two general types of expanded terminal bonds.

431. The steel core bond comprises a soft steel center inserted in a copper head and so designed that when placed in the rail and pressure applied, the

expansion of the steel core center will force the copper head into close contact with the rail. This type of bond has been largely superseded by the all copper bond.

432. The **second type of expanded terminal bond** comprises two solid copper heads or terminals into which is forged a laminated copper conductor joining the two. When the bond is in place and pressure applied, the soft copper head is expanded into close contact with the rail. Bonds of the expanded terminal type are designed for use either beneath the fish plate or under the flange of the rail, or are made of sufficient length to span the fish plate. Where the conductor joining the terminals is of considerable length as in cross bonding, it is sometimes made of solid copper wire but a stranded or laminated conductor is absolutely necessary where the bond is short and must conform to rail deflection at the joint.

433. Soldered bonds have been introduced, in some cases successfully, and comprise a laminated copper conductor terminating in two solid heads joined to the rail by soldering, brazing or welding. The bond is attached to the head of the rail on the outside or to the flange of the rail. In either case it is exposed to view, which facilitates inspection and renewals but also renders the bond liable to theft. It is difficult to obtain a contact by soldering that will withstand constant vibration, but brazed and welded bonds appear to be freer from this objection. Where good contact can be secured the accessibility and cheapness of this method of bonding recommends it.

434. Both the expanded terminal and soldered bonds are universally used for bonding the track and third rail of city and interurban electric railway systems. While the soldered bond is cheaper and has many qualities recommending its adoption, its use on T rails laid on surface ties is open to the objection that it is relatively easy of removal which renders it liable to theft. Hence the expanded terminal bond, placed beneath the fish plate is preferable with an exposed rail.

435. The selection of bonding for a given road depends both upon current capacity and contact resistance desired, and is determined by the class of service involved.

436. The contact resistance of a single 9-inch 4/0 bond of expanded terminal type in good condition is approximately 0.00003 ohms. Hence the relative resistance of bonded joints and track itself is approximately as given in (**437**).

437. Resistance per Mile of 70 lb. Track, Including Bonds.

1 Mile 70-lb. track (2 rails) at 19 microhms per centimeter cube*..	= 0.0361 ohms
Single bonding 176 joints at 0.000015 ohms (2 rails).......	= 0.0026 "
Total per mile of bonded track.........................	= 0.0387 ohms

438. It is evident from (**437**) that the joint resistance of a well bonded rail is relatively low compared with the total resistance of the rail itself, but the proportion holds only when the bonding is installed and maintained in **first class** condition.

439. Double bonding is resorted to in many instances in order to insure a path of good conductivity in case of failure of a single bond. Where double bonding is not required to provide additional current capacity in order to keep temperature rise within reasonable limits, it is better engineering to install a single bond of sufficient capacity from a temperature rise standpoint and maintain this bonding in good condition. Double bonding is open to the objection that one of the two bonds may give imperfect contact and be practically useless, and such a method of installation usually results in the operation of the road with practically single bonding throughout.

440. Single **bonding for suburban roads** where the service is infrequent and current demands do not exceed momentarily 1000 amperes, is to be recommended provided rails are frequently cross bonded and all bonded joints are regularly inspected and maintained in their original good condition.

441. The heating of bonds will determine the size and number of bonds to be used on roads over which there is a large volume of traffic, and where the moving units demand a large kilowatt input, such as trains hauled by locomotives, etc.

Meaning cube whose side = 1 cm.

442. Heating of 9-inch 4/0 Bonds (see 443).

Current amperes.	500	1000	1500	2000	2500
Temperature rise degrees C.	10	35	78	135	210

443. Table (**442**) of heating constants applies only to bonding exposed to the air and not covered by fish plate, in the latter case the heating will be somewhat increased. The values given in the table apply only to bonds maintaining good contact with the rail. As one of the rails composing the track return may become useless owing to failure of a single bond, each rai must be bonded with the prospect of carrying the full return current. Moreover, as the heating of the bond varies approximately proportionally with the square of the current value and extremes in temperature are to be avoided owing to the unequal expansion of copper and rail, it is desirable that the greatest conservatism be used in selecting the bonds for a given service. This holds especially true where soldered bonds are concerned, as too high a temperature will melt the connection between rail and bond. Brazed and electrically welded bonds will of course, stand a larger current value and higher temperature without danger of falling off.

444. Amalgam bonds have been used with some success, the most modern comprising a spiral spring approximately 1 inch in diameter containing a soft amalgam, the whole being designed to be placed between the thoroughly cleaned fish plate and rail, and held in place by the bolts extending between them. This type of bonding is easy of application and is useful where a concealed bond is desired.

445. Welded joints in general give the greatest satisfaction where it becomes necessary to bond the rail to its full current carrying capacity as when the bond is called upon to carry a very high value of current. Welding is obtained by three methods: Cast, electric and thermit welding.

146. Cast welding is secured by pouring the metal in a mould surrounding the rail joint thoroughly cleaned for the purpose. Such joints will have no expansion, are somewhat liable to crack, and are best suited for use in city streets where the track is held rigidly in place by the pavement.

447. Thermit welding is obtained in somewhat like manner except a relatively small amount of metal is required and the process is not as yet in very general use.

448. Electric welding at the rail joint is perhaps best secured by welding a steel strap to each rail, the joint not being continuous between strap and rail but maintained at one or two points of contact.

449. Electric welding has proved very satisfactory in the past and gives good satisfaction where great current carrying capacity is desired.

450. All forms of welding are necessarily somewhat expensive and are not well adapted to the requirements of suburban roads using T rails laid on ties in the open on account of the inability of such joints to allow for rail expansion.

451. Third Rail Construction: Bill of Material and Approximate Cost of Installation.

Cost per mile, top contact 70-lb. 33-ft. Third rail, not protected; four supports per rail.

Quantity	Material	Cost Unit	Cost Total
160	70-lb. A S C E rails (special comp.)	$35.00	$2,156.00
320	2-bolt splice bars	0.15	48.00
640	Nuts and bolts for splice box	0.03	20.00
640	Malleable iron cups and lags	0.06	39.00
640	Reconstructed granite insulators	0.40	256.00
640	Extra for sawed long ties	0.50	320.00
320	Rail bonds	0.70	224.00
12	Approach blocks	4.00	48.00
5	Anchors	5.00	25.00
	Miscellaneous supplies		29.00
	Total material		$3165.00

Labor.

451.—(*Concluded.*)

640	Installing ties	0.35	$224.00
640	" cups, etc.	0.03	19.00
1 mile	" rails		75.00
320	" bonds	0.55	176.00
12	" approach blocks	0.50	6.00
	distributing material, ties, rails, etc.		175.00
	Total for labor		$675.00

For jumpers at crossovers and street crossings allow 300 ft. of 1,000,000-cir. mil cable per mile. When this is installed in fiber conduit embedded in concrete, cost will be approximately $1.80 per ft.

Total for jumpers	$ 540.00
Engineering and superintendence	400.00
Total cost per mile	4780.00

452. Cost per Mile Top Contact 70-lb. Third Rail, Protected. 33-ft. Rails, Four Supports per Rail.

Quantity	Material	Cost Unit	Cost Total
160	70-lb. A S C E rails (special comp.)	$35.00	$2,156.00
320	2-bolt splicing bars	0.15	48.00
640	Nuts and bolts for splice box	0.03	20.00
640	Malleable iron cups and lags	0.06	39.00
640	Reconstructed granite insulators	0.40	256.00
640	Extra for sawed long ties	0.50	320.00
320	Rail bonds	0.70	224.00
12	Approach blocks	4.00	48.00
5	Anchors	5.00	25.00
800	Sets protection supporting castings	0.25	200.00
800	Posts	0.08	64.00
800	Pc. board 1¼ in. x 10 in. pine (capped)	0.40	320.00
800	Sets Hardware	0.06	48.00
	Miscellaneous supplies		30.00
	Total material		$3,798.00

Labor

640	Installing ties	0.35	224.00
640	" cups, etc.	0.03	19.00
1-mile	" rails		75.00
320	" bonds	0.55	176.00
12	" approach blocks	0.50	6.00
1-mile	" protection		200.00
	Distributing material		200.00
	Total for labor		$900.00

For jumpers at crossovers and street crossings allow 300 ft. of 1,000,000-cir. mil cable per mile. When this is installed in fiber conduit embedded in concrete, cost will be approximately $1.80 per ft.

Total for jumpers	$ 540.00
Engineering and superintendence	500.00
Total cost per mile	5,738.00

453. Bill of Material and Cost per Mile Protected Underrunning Third Rail.

70 lb. per yd. 33-ft. rails; four supports per rail.

Quantity	Material	Cost Unit	Cost Total
160	70 lb. special bull head rail	$35.00	$2,156
320	2-bolt splice bars	0.15	48
640	Nuts and bolts for splice bars	0.03	20
640	Malleable iron brackets and hook bolts	0.40	256
640	Pairs insulators	0.40	256
1920	Lag screws	0.02	38
4400	Ft. wooden protection	40.00	176
640	Extra for sawed long ties	0.50	320
320	Rail bonds	0.70	224
12	Approach blocks	4.00	48
	Miscellaneous supplies		28
	Total material		$3,570
	Labor		
640	Installing ties	0.35	224
640	" brackets	0.10	64
1-mile	" rails and protection		250
320	" bonds	0.55	176
12	" approach blocks	0.50	6
	Distributing ties and rails		150
	" other material		50
	Total for labor		920

For jumpers at crossovers and street crossings 300 ft. of 1,000,000-cir. mil. cable per mile. When this is installed in fibre conduit embedded in concrete cost will be approximately $1.80 per ft.

Total for jumpers	540
Superintendence and engineering 10 per cent	505
Total cost per mile installed	$5,535

454. Approximate Cost of Installation for 600-Volt d.c. Span Construction.

Cost per mile:

Based on 100 ft. pole-spacing on tangents—wooden poles—standard d c. construction—allowance made for 10 per cent track curvature—track and road bed not included.

	Single Track	Double Track
Poles, 35 ft. long, 8 in. tops at $5.50	$620.00	$620.00
Line material	325.00	450.00
Wire and cable exclusive of trolley	126.00	189.00
Trolley wire 4/0 at 26½ cents	903.00	1,806.00
Material	$1,974.00	$3 065.00
Labor	1,050.00	1,450.00
Labor and material	$3.024.00	$4,515.00
Engineering and superintendence	302.00	451.00
Total cost per mile	$3,326.00	$4,966.00

455. 600-Volt d.c. Trolley Bracket Construction.

Cost per mile:

Based on 100 ft. pole-spacing on tangents—wooden poles—standard direct current construction—allowance made for 10 per cent curvature—track and road bed not included.

	Single Track	Double Track
Poles, 32 ft. long 8 in. tops at $4.75	$269.00	$307.00
Line material	250.00	500.00
Wire and cable exclusive of trolley	73.00	115.00
Trolley wire 4/0 at 26½ cents	903.00	1,806.00
Material	$1,495.00	$2,728.00
Labor	775.00	1,290.00
Material and labor	$2,270.00	$4,018.00
Engineering and superintendence	227.00	402.00
Total cost per mile	$2,497.00	$4,420.00

456. 600-1200-Volt d.c. Catenary Trolley Bracket Construction.

Cost per mile:

Based on 150 ft. pole-spacing on tangents—11 suspensions per span wooden poles—side brackets for single track and double brackets for two tracks—track and road bed not included—allowance made for 10 per cent curvature.

	Single Track	Double Track
Poles, 35 ft. long, 8 in. tops at $5.50	$209.00	$235.00
Line material	350.00	700.00
Wire and cable exclusive of trolley	175.00	350.00
Trolley wire 4/0 at 26½ cents	903.00	1,806.00
Material	$1,637.00	$3,091.00
Labor	800.00	1,400.00
Labor and material	$2,437.00	$4,491.00
Engineering and superintendence	244.00	449.00
Total cost per mile	$2,681.00	$4,940.00

457. 6600-11,000-Volt a.c. Construction.

	Single Track	Double Track
Total cost per mile	$3,230.00	$5,475.00

458. 6600-11,000-Volt Span Catenary Trolley Construction.

Cost per mile:

Based on 150 ft. of full spacing on tangents—wooden poles—track and road bed not included—11 suspensions per span—allowance made for 10 per cent curvature.

	Single Track	Double Track
Poles, 35 ft. long 8 in. tops at $5.50	$418.00	$418.00
Line material	400.00	725.00
Wire and cable, exclusive of trolley	200.00	350.00
Trolley wire 4/0 at 26½ cents	903.00	1,806.00
Material	$1,921.00	$3,299.00
Labor	900.00	1,500.00
Labor and material	$2,821.00	$4,799.00
Engineering and superintendence	282.00	480.00
Total cost per mile	$3,103.00	$5,279.00

459. Cost of Installation of 6600-11,000-Volt a.c. Catenary Construction Supported by Steel Bridges.

Cost per mile:

Based on 300 ft. spans—double messenger—allowance made for 10 per cent track curvature—track and road bed not included.

Cost per mile for four tracks.	
19-Steel bridges including erection and foundation at $850.00...	$16,150.00
Trolley line material	1,600.00
Wire and cable exclusive of trolley	1,200.00
Trolley wire 4/0 at 26½ cents	3,612.00
Material	$22,562.00
Labor (exclusive of erection and foundation)	3,200.00
Labor and material	$25,762.00
Engineering and superintendence	2,500.00
Total cost per mile for four tracks	$28,262.00
Total cost per mile for each track	7,065.00

Cost per mile for six tracks	
19-Bridges in place at $1250.00	$23,750.00
Trolley line material	2,400.00
Wire and cable—exclusive of trolley	1,800.00
Trolley wire 4/0 at 26½ cents	5,505.00
Material	33,455.00
Labor (exclusive of bridges)	4,800.00
Material and labor	$38,255.00
Engineering and superintendence	3,000.00
Cost per mile for six tracks	$41,255.00
Cost per mile for each track	6,876.00

460. Bill of Material and Cost of 33,000-Volt Single-Phase Transmission Line.

On same poles as a.c. trolley 150 ft., spacing on tangents—40-ft. poles; 5/6 in. steel cable for lightning protection.

Quantity	Material	Cost
40	Extra cost of poles	$80.00
40	Cross arms 5 ft. 6 in. x 4 in. x 5 in	24.00
80	Braces 2 in. x ¼ in. x 2 ft	12.80
40	Bolts for cross arms ⅝ in. x 14 in	10.00
80	Bolts for braces ⅜ in. x 6 in	4.80
40	Lags for braces and poles ⅜ in. x 6 in	1.80
40	Parts for attaching ground wire to pole	1.60
80	Insulators and pins	72.00
30-lb.	No. 8 B. & S. ties	8.10
20-lb.	No. 6 B. & S. for ground connections	5.40
5300 ft.	5/16 in. galvanized cable for ground wire	53.00
1000 ft.	⅜ in. galvanized cable for guys (rest incl. in trolley)	14.00
5	Splicing sleeves	1.25
	Solder, etc	5.00
	Material for doubling, arming at curves, etc	50.00
	Material exclusive of wire	$343.75
	Wire 2 miles No. 2 B. & S. at 25.5 cents	541.00
	***Total material* per mile**	$884.75

	Labor	
40	Additional for erecting longer poles	20.00
40	Gaining roofing and setting cross arms	30.00
	Pulling and tieing in 2 trans. wire	50.00
	" " " " 1 ground wire	35.00
	Extra guying and grounding cable	10.00
40	Distributing poles extra for long poles	10.00
	Telephone cradles, etc	20.00
	Distributing material other than poles	10.00
	Total for labor	185.00
	Labor and material	$1069.75
	Engineering and superintendence	55.25
	Total cost per mile	$1,125.00

461. Bill of Material and Cost of 33,000-Volt Three-Phase Transmission Line.

On same poles as d.c. trolley 100 ft. spacing on tangent—40-ft. poles, 5/16-in. steel cable for lightning protection—3 wires on one cross-arm—3 ft. between wires.

Quantity	Material	Cost Unit	Cost Total
60	Extra cost of poles	$2.00	$120.00
60	Cross arms 5 in. x 6 in. x 10 ft. 6 in	1.00	60.00
120	Braces 2½ in. x ¼ in. x 3 ft. 6 in	0.22	26.40
60	Bolts for cross arms ⅝ in. x 14 in	0.25	15.00
120	Bolts for braces ⅜ in. x 6 in	0.06	7.20
60	Lags for braces and poles	0.045	2.70
60	Parts for attaching ground wire	0.04	2.40
180	Insulators and pins	0.90	164.00
40	Lb. No. 8 B. & S. insulator ties 4 ft. long	0.255	10.20
30	Lb. No. 6 B. & S. tinned copper for grooved connections	0.255	7.65
5300	ft. 5/16 in. galvanized cable for ground wire	0.01	53.00
1000	ft. ⅜ in. galvanized cable for guy (rest included with trolley material)	0.014	14.00
8	Splicing sleeves, solder, etc		7.00
	Material for double arming at curves		50.00
	Material exclusive of wire		$539.55
	Wire 3 miles No. 2 B. & S. at 25.5 cents		815.00
	Total material per mile		$1,354.55
	Labor.		
60	Additional for erecting longer poles	0.50	30.00
60	Gaining roofing and setting cross arms	0.75	45.00
	Pulling and tieing in 3 trans. wires	20.00	60.00
	" " in 1 ground cable		35.00
	Extra guying and grounding ground cable		10.00
60	Distributing poles—extra for long poles	0.25	15.00
	Distributing material other than poles		12.00
	Telephone cradles, etc		20.00
	Total for labor		$227.00
	Labor and material		$1,581.55
	Engineering and superintendence		55.45
	Total cost per mile		$1,637.00

462. Bill of Material and Cost of 33,000-Volt Three-Phase Duplicate Transmission Line.

Two circuits on one pole—42 in. between wires—5/16-in. galvanized steel cable for lightning protection—40 ft. poles 125-ft. spacing.

Quantity	Material	Cost Unit	Cost Total
45	40-ft. chestnut poles 8 in. tops	$7.00	$315.00
45	Cross arms 12 ft. x 4½ in. x 6 in	1.75	78.75
45	Cross arms 8 ft. 6 in. x 4 in. x 6 in	1.25	56.25
90	4 ft. x 5/16 in. x 2 in.—braces	0.28	25.20
90	3 ft. 1 in. x ¼ in. x 2 in. braces	0.20	18.00
90	Bolts for cross arms 1 in. x 14 etc	0.25	22.50
180	Bolts for braces ⅝ in. x 6 in	0.045	8.10
90	Lags for braces ⅝ in. x 5 in	0.04	3.60
90	Staples and washers for attaching ⅝ in. cable		5.00
270	33,000-volt insulators	0.55	148.50
270	Insulator pins	0.35	94.50
3000	Ft. ⅜-in. guy cable galvanized	0.014	42.00
5300	Ft. ⅝-in. lightning protective cable galvanized	0.01	53.00
75	Lb. No. 8 B. & S. copper wire for ties	0.25	18.75
	Splicing sleeves, solder, etc		10.00
	Material for double arming at curves		75.00
	Material exclusive of wire		974.15
	Wire 6 miles No. 2 B. & S.	0.255	1,630.00
	Total Material per mile		$2,604.15
	Labor		
45	Distributing poles	1.00	45.00
45	Digging holes	1.50	67.50
45	Setting poles	1.75	78.75
	Guying and anchoring		40.00
	Running and tieing in 6 miles trans. wire	0.20	120.00
	Running and tieing in 1 mile 5/16-cable		35.00
	Distributing material		25.00
90	Gaining roofing and setting cross-arms	0.75	57.50
	Lightning arrester grounds		20.00
	Total for labor		488.75
	Labor and material		$3,092.90
	Engineering and superintendence		300.00
	Total cost per mile		$3,392.90

SUB-STATIONS.

463. The use of the synchronous or rotary converter for converting three-phase a.c. to 600 volts d.c. is almost universal both for a supply frequency of 25 cycles and 60 cycles. The location and capacity of such stations depends upon the character of the service and local considerations, but the type of apparatus used is similar whether the sub-stations be located in the city to supply many small car units, or on interurban lines to supply perhaps but one or two high speed cars or trains of several such cars.

464. While the general arrangement and type of apparatus is similar in all sub-stations there are two minor points of difference leading to the division of sub-station into two classes.

1. The use of compound or shunt converters.
2. *Starting from the a.c. or d.c. side.*

465. *The* use of the **compound synchronous converter** with series *field is restricted more especially to those systems in which the station output*

is very fluctuating such as experienced in sub-stations feeding suburban and interurban railway systems or city systems in which heavy trains accelerate at a rapid rate.

466. The plain **shunt-wound converter** has a restricted field in sub-stations supplying city service lines where the individual units are small and where a single sub-station feeds a large number of such units, thus producing a uniform load curve with small momentary fluctuations. The compound winding of converters is generally adjusted for flat compounding at 600 volts throughout the range in load, and this is best secured in conjunction with inductive coils placed in series with the transformer secondaries. Artificial inductive reactance is introduced in rotary converter sub-stations both in order to secure flat potential on the d.c. side on all loads and unity power factor on the a.c. side at all loads.

467. Starting of synchronous converters is accomplished by one of three methods.

First: d.c. starting through rheostat.

Second: a.c. starting by induction motor.

Third: a.c. starting from transformer taps.

468. Starting from the d.c. side occasions no disturbance in the primary distributing system and recourse is had to this method of starting more especially when 60-cycle converters are fed from a primary distribution system which also carries a lighting load. This method of starting is open to the objection that synchronizing is required, which may sometimes be difficult owing to the possible fluctuations in the d.c. voltage supply. In extreme cases the delay from this cause may be considerable.

469. Starting from the a.c. side is sometimes effected through the medium of an induction motor having its armature mounted upon an extension of the converter shaft. This method of starting while free from the delays caused in d.c. starting due to possible variations in d.c. potential, nevertheless requires synchronizing of the converter. Owing to the perfecting of methods of starting converters directly from transformer taps the introduction of an induction motor for starting purposes becomes a needless expense and is moreover a slower method of starting than method No. 3.

470. Starting rotary converters from the a.c. side with a reduced potential obtained from transformer taps is the recognized method of starting in universal use, and in 25-cycle systems starting may be affected by this means without drawing more than full load current from the primary. The advantages of a.c. starting are cheapness of installation and a minimum amount of time required to throw the converter into service, no synchronizing being necessary.

471. Instructions for Starting Synchronous Converters from Alternating Current Side.

1. See that all switches (except main negative on machine) are open.
2. Close line switch feeding buses.
3. Close high tension transformer switch.
4. Close starting switch on low voltage taps—upper throw, as converter reaches synchronous speed (as shown by beats of the d.c. voltmeter).
5. Close equalizer switch.
6. Close series-shunt switch; if other converters are carrying load the separate excitation of series field, through the equalizer, will tend to give correct polarity. If polarity is reversed it should be corrected by the field-break-up reversing switch. Down throw of the switch causes armature to slip back one pole, thus changing polarity. As soon as armature passes the dead center (as shown by voltmeter needle at zero) the break-up switch should be opened from the down throw. Down throw of the switch is not a running position; it is used only during the operation of correcting a reversed *polarity. When* polarity is correct,
7. *Close field*-break-up switch—upper throw; bring converter to full *voltage.*
8. *Throw starting* switch—quickly—from upper to lower throw.

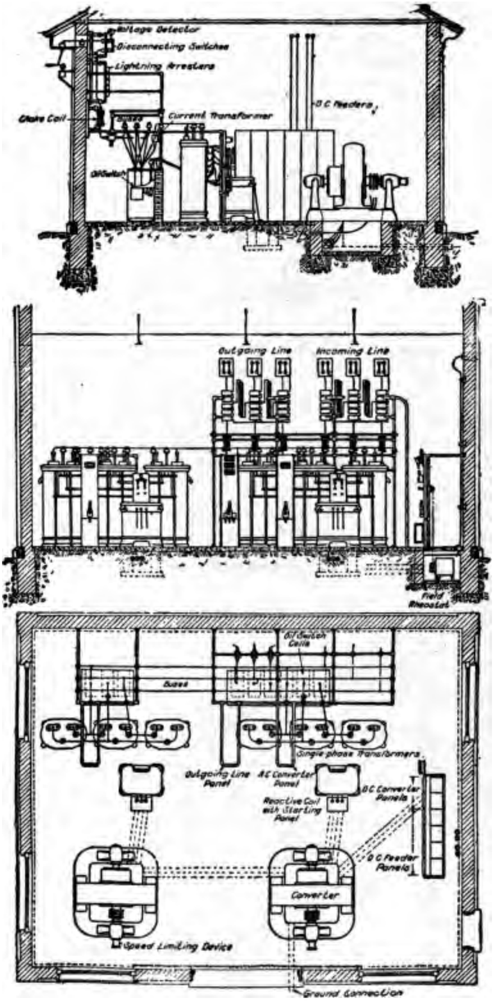


FIG. 117.—Synchronous converter sub-station.

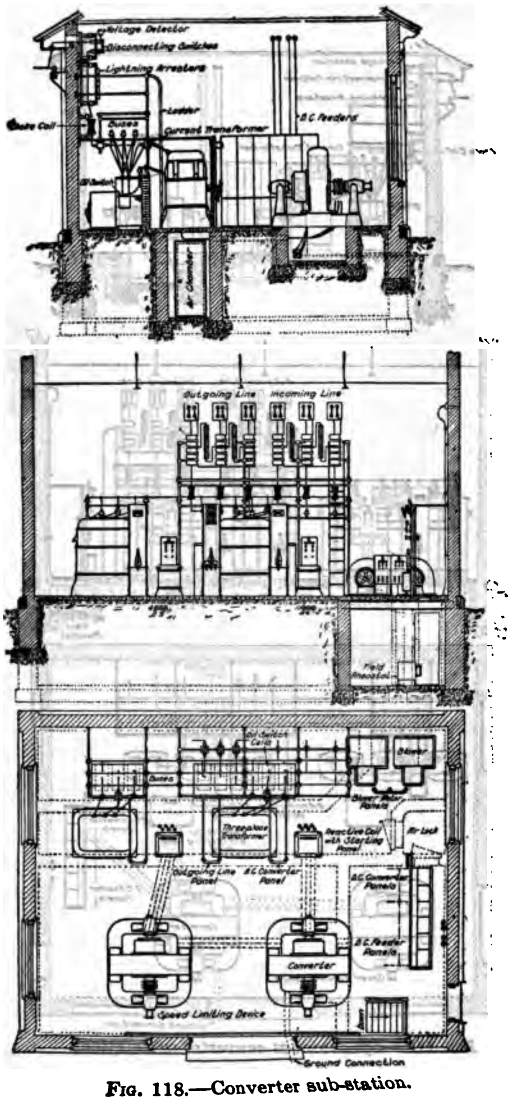


FIG. 118.—Converter sub-station.

9. Close d.c. circuit breaker.

10. Adjust field rheostat.

11. Close main switch; make further adjustments of field rheostats to obtain desired division of load, power factor and voltage.

472. Equipment of Synchronous Converter Sub-Stations.

1. Incoming and outgoing primary feeders provided with disconnecting switches and lightning arresters.

2. High tension bus bars with automatic oil switches controlling same.

3. Current transformers in the primary conductor circuit and feeding ammeters and relays for operating switches.

4. Step-down transformers either of the air-blast or oil-cooled type.

5. Inductive coils connected in the transformer secondary circuit, extending to the a.c. side of the converters.

6. Synchronous converters.

7. D.c. outgoing feeders.

8. Switchboard panels controlling both the a.c. and d.c. side of the converter as well as both a.c. and d.c. incoming and outgoing feeders.

473. Synchronous converters are designed to operate both three-phase and six-phase depending upon the capacity and frequency of supply.

474. Standard Capacity 25-Cycle Synchronous Converters.

200 kw	Three-phase
300 "	" "
400 "	" "
500 "	Six-phase
750 "	" "
1000 "	" "
1500 "	" "
2000 "	" "

475. Standard Capacity 60-Cycle Synchronous Converters.

100 kw	Six phase
200 "	" "
300 "	" "
500 "	" "

476. Ratio of conversion varies somewhat with the construction of the converter, being in general as follows:

Three-phase converters	370 volts a.c. to 600 volts d.c.
Six-phase converters	430 volts a.c. to 600 volts d.c.

477. Machines having long pole arcs have a somewhat higher ratio of conversion than those of shorter pole arcs; and in order to provide for the differences in types of machines and also for the varying drops in the primary distribution system to which rotary converter sub-stations are connected, it is customary to provide five primary taps of 2.5 per cent. each in the step down transformers, one of these taps being 2.5 per cent. above the receiving potential in order to take care of the high ratio of conversion of longer pole arc converters.

478. Thus a **typical step-down** transformer will have primary and secondary **ratios** as follows:—

Primary Voltages 19,600—19,100—18,600—18,150—17,700—17,200

Secondary Voltage 370

Such a transformer would be adapted to operate a three-phase 25-cycle rotary converter from a "Y" connected 33,000-volt transmission line.

479. Standard Primary Sub-Station Voltages.

11,000 volts
19,100 "
33,000 "
66,000 "

480. It is customary to use delta transformer connections for both 11,000 and 19,000 volts and " Y " transformer connections with grounded neutral for 33,000 volts and higher.

481. Many sub-stations now operating at 19,100 volts delta are doing so temporarily pending a change to 33,000 volts " Y " for which higher potential the transformers are insulated.

482. Step-down transformers are of several **types,** as follows:

A. B. or air-blast transformers,

O. C. or oil-cooled transformers,

W. C. or water-cooled transformers,

Oil transformers self-cooled,

F. O. or forced oil transformers.

Any or all of these several types of step-down transformers can be built three-phase or single-phase, in which latter case three transformers are required for either " Y " or delta connection with each converter.

483. Air-blast transformers when used call for the construction of an air chamber over which they are placed and from which they receive air at a pressure of from one-half ounce to one ounce. Air is supplied by a duplicate motor-driven fan feeding into the air chamber. This type of transformer is very generally used up to and including potentials of 33,000 volts.

484. For higher potentials and for small transformer units oil is resorted to for cooling by a variety of means.

485. The design of the **small self oil cooled transformer** is especially adapted to the smaller sizes owing to its cheapness. For larger sizes it becomes necessary to cool the oil either by means of a cooling coil placed in the transformer and through which water is circulated, or by providing means of circulating the oil itself through an outside pipe coil in order to reduce its temperature.

In general the air-blast type of transformer is preferred for potentials not exceeding 33,000 volts on account of its freedom from fire risk in case of a short circuit or burn out. For very small single converter units or those having connection to the higher primary potentials some form of oil cooled transformer is to be preferred.

486. The general arrangement of apparatus in sub-stations is somewhat similar in all cases as such buildings are generally designed for the purpose. In general the wiring scheme consists in providing the shortest and most direct path from the incoming primary lines to the outgoing d.c. feeders, and the interior wiring scheme is carried out with the object in view to prevent any crossing of circuits or doubling back upon themselves.

487. This purpose is accomplished in the typical arrangement shown in Fig. (117) in which the incoming lines lead directly to the high tension bus through an intermediate oil switch, thence to the primary of the transformer, from the transformer secondary through the inductive coil to the a.c. side of the converter, from the d.c. side of the converter to the converter panel, feeder panels, and outgoing d.c. feeders. This arrangement leads to a perfect separation of high-tension and low-tension leads, keeping the former entirely back of the transformers, thus making it impossible for the operator to come in contact with the high potential circuit as long as he remains in the operating section of the station.

488. Duplicate apparatus in a sub-station may or may not be installed, depending upon local requirements. The manufacture of synchronous converters, transformers, and general sub-station apparatus, has been so far perfected that failures in such apparatus are very infrequent and it is often customary to install sub-stations containing but a single converter and set of transformers, although it is always good engineering to provide duplicate converter, transformers, switchboard, etc., throughout. This practice is largely influenced by local requirements of absolute continuity of service, and also by the development of the so-called portable sub-station, which is now furnished in units as large as 500 kw.

489. Portable sub-stations, so-called, comprise a synchronous converter, step-down transformer, and switchboard apparatus, mounted in a box car

and intended to be moved from place to place as occasion demands, thus serving as a reserve to be used in case of failure or overload of any sub-station in the system.

490. A compact arrangement of the apparatus involved has been perfected so that portable units of 500 kw. capacity can be constructed, the complement of apparatus is identical with that in the standard sub-station, and the arrangement is such as to provide sufficient room for the operator. As such

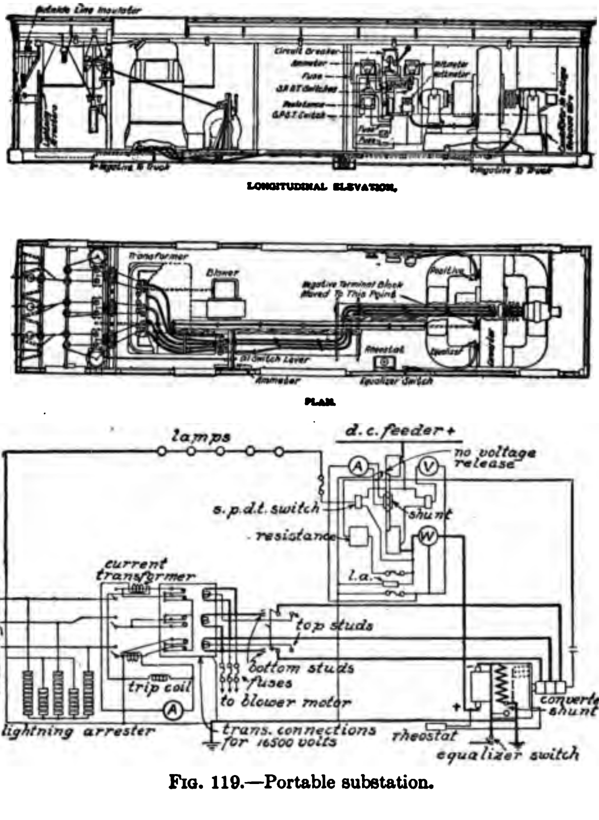


FIG. 119.—Portable substation.

sub-stations are not intended for any fixed location, they are not equipped for both incoming and outgoing primary lines but are designed to be connected to an unbroken primary circuit. The converters may be compound wound and provided with equalizing switch so that a portable sub-station may serve as an auxiliary to a stationary sub-station in case of extreme sustained overload.

491. A.c. sub-stations designed for use with a.c. railway motor equipments are generally designed for operation without attendant. Such sub-

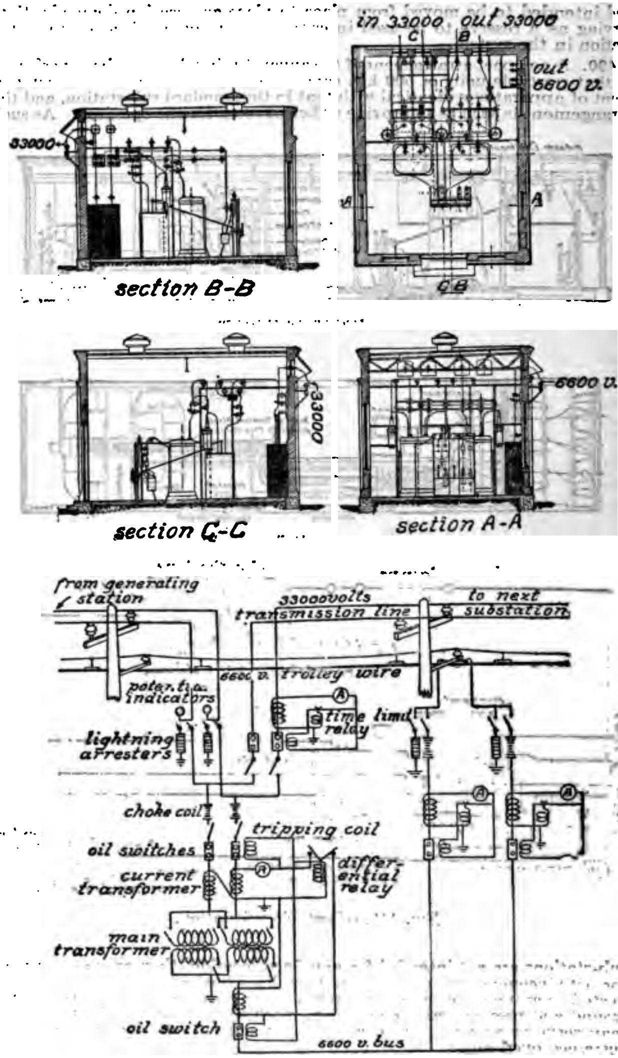


FIG. 120.—Transformer sub-station.

stations comprise a small fireproof building containing step-down transformers, generally in duplicate, together with the necessary switchboard apparatus. Both primary and secondary transformer circuits are provided with automatic oil switches designed to open on short circuit or extreme overload only, thus serving merely as a safety device to protect the transformers from burn out. As such sub-stations have no operator and are subject to violent fluctuations in load greatly exceeding the average, it is necessary that all protective devices be limited in their function to guard against short circuit and not overload.

492. In order to facilitate the location of faults, a.c. transformers substations are commonly supplied with both voltmeter and ammeter besides being equipped with lightning arresters upon both the high and low tension incoming and outgoing feeders. Step-down transformers are of the self-cooling oil type.

RAILROAD SIGNALS.

493. With the growth of traffic and the increase in speed of equipments now employed on railroads in this country has come the necessity for providing additional safe guards in the method of conducting traffic. At the present time most of the steam railroads have found that the traffic has increased to such an extent that the old method of operating trains by train orders and telegraph is so arduous a task for the train dispatcher that it is imperative to shorten his hours of duty as well as his division.

494. In the **method of operating trains by telegraph** a train order is a blank filled out by a station master in response to telegraphic orders received from the train dispatcher and handed to the engineer and conductor of every train affected by the order. The possession of this order is the engineer's authority for running his train, but before he proceeds he must telegraph the train dispatcher his understanding of the order so as to minimize the chances of error. After the train has left, the operator at that station notifies the train dispatcher, who enters the name of the station and time on a sheet before him so that he can tell at a glance where every train on the division is and how to direct their movements.

495. With this system it is only essential that a man stand ready to receive messages and wave a red flag or hoist a signal to a mast head if it is desired to stop a train at any particular station to await train orders, but the chance of error on the part of the train distpacher or telegraph operator increases very rapidly with the number of train movements recorded, and for this reason a system of signalling has been developed whereby trains automatically set signals behind them to prevent following trains approaching too closely. The trains dispatcher's duties are thus greatly reduced inasmuch as he is only required to keep a record of their positions, so as to stand ready to relieve confusion in case of failure of the signals.

496. Block signals on double-track roads: by the use of two signals or semaphores on the same post, the engineer can tell when to run cautiously or stop. Thus when one signal is set at danger and the other at clear, the engineer knows the block before him is clear, but the one beyond is occupied. He then proceeds, expecting to find both of the next signals at danger indicating that there is a train in the next block and he must stop. One of the signals on the post is therefore known as a distant signal since it indicates the position of a signal one block in advance, and the other is known as the home signal.

497. The distant signal is interlocked with the home signal so that it cannot show clear until the home signal a block in advance has cleared. The reason why one signal at the beginning of a block does not provide sufficient protection for trains when running at high speed is because it cannot be seen in time to make a stop with the ordinary service application of brakes without running by a signal. The distant signal, therefore, serves to forewarn the engineer by repeating the indication of the home signal far enough in the direction of an approaching train to enable a stop to be made under the worst conditions before the home signal is reached. It is evident, therefore, that this signal should be placed at least 1500 or 2000 ft. from the home signal on a level track, a little less on an up grade and a greater distance on down grades.

498. The length of a block will depend upon the headway and speed of the train, but is always of sufficient length to allow the engineer to gain control of his train and stop before reaching a home signal after the distant sig-

nal is seen. On roads where the traffic is heavy the blocks are made short so that a train may run through the block quickly and not hold it against another train which may be waiting. Likewise, a high speed train will run through a longer block in the same time a slow speed train will run through a short block, hence for high speed trains the block should be made longer, requiring fewer signals for a given length of track and affording greater safety as the trains are kept further apart. When the blocks are long and the train would be allowed to run at full speed after passing the distant signal (set at danger), it is customary to place an intermediate distant signal far enough in advance of the home signal to permit a stop being made before the home signal is reached. This method is particularly advantageous in case the home signal is at the end of a long curve or the contour of the country is such as to prevent its being seen before it is too late to stop. In the case of very long blocks it is customary to omit the distant signal at the beginning of the block, the intermediate signal affording ample protection.

499. Of the many signals in use at the present time, the **semaphore type is** undoubtedly the most popular, and the tendency now is to adopt this type as the standard. A semaphore is a narrow blade pivoted near one end to an upright post at a convenient height so that it may be clearly seen at a distance. The short end of this blade is fitted with a light casting with two or more holes for inserting colored bull's-eyes of sufficient size to permit of their being seen at a distance at night when a light is placed behind them. This blade is suitably connected by means of a connecting rod to a mechansim usually in the base of the post so that it can be turned around its pivot through an angle of about 60 degrees. In the horizontal position the semaphore indicates danger, stop, and when pointing downwards indicates clear. In the day time the engineer is governed by the position of the blade, whereas at night a light is made to shine through a red bull's-eye for danger and through a green bull's-eye for clear. The adoption of a green light to indicate clear instead of a white light has been occasioned by the fact that white lights in the vicinity of the signal were often mistaken at a distance for the signal when the signal light was out, and in the case of a broken red glass a clear indication will be given instead of danger.

500. A number of railroads have adopted what is known as the **three-position semaphore** to take the place of a home and distant signal located on one post. The horizontal position indicates that the block is occupied, 45 degrees position indicates caution, and vertical position clear. At night a red light indicates danger, a yellow light caution and a green light clear. Another semaphore which is becoming quite popular points upward instead of downward to indicate clear. Such a blade requires no counterweight and will tend to fall to the stop position if accident occurs to prevent its normal operation. If it becomes covered with snow and sleet it is somewhat easier to operate.

501. Any of the above **signals** may be **operated** by means of levers located in the switchman's tower and suitably connected with the signal through bell cranks and connecting rods or steel wires, or even by compressed air controlled by electrically operated valves, but such a system requires the constant attendance of an operator to properly set the signals. The physical effort required to operate mechanically controlled signals limits the distance at which they can be placed from the tower, and in case of compressed air it is necessary to supply a suitable air compressor equipment for each tower. Signals when thus operated will necessarily be placed further apart and distant signals must be dropped from the same pole as the home signals and placed near the tower from which they are controlled. In this instance the signals are so placed that the sections they control overlap, that is a certain short section will be controlled by two signals, one at the beginning of one block and the other at the beginning of the next block, so that if a train should break down immediately after passing a signal the preceding signal could not clear; thus an approaching train would be sufficiently warned to prevent its colliding with the disabled train.

502. The temptation, however, to allow two trains to occupy a long block in case of a disarrangement of schedule is considerably greater than to allow two trains to occupy a short block. Hence on account of the advantages possessed by the automatic block system, the blocks may be made shorter and additional safety be secured by eliminating the personal equation of the operator.

503. Fig. 121 shows diagrammatically the system of **track circuits employed on steam railroads** at the present time. At the beginning of eaeh block the rails are insulated from the preceeding section so as to form an insulated section known as a block. At one end of the section is a closed circuit battery of sufficient capacity to operate a relay at the other end of the block. This relay opens and closes a secondary circuit through a second battery which operates the mechanism moving the signals. This mechanism usually consists of a small series motor connected with the semaphore shaft through triple-reduction gearing and a proper controlling device, whereby the motor is cut out and the signal held in position by means of an electrically operated pawl or lock. The signal may, however, be operated by means of gas stored in a tank in the base of the signal post; this method of operating signals, however, is not considered as satisfactory as the electrical method.

504. When there is no train in the block, the track circuit current energizes the relay which closes the operating circuit, restoring the home signal to clear and locking it in place. After the train has passed the next block, the home signal in advance returns to clear and closes the interlocking circuit which holds the distant signal at the beginning of the preceeding block at danger, thereby allowing it to return to clear.

505. When a train first enters a block the front pair of wheels short circuits the rails causing the relay to open and the holding pawls to drop out. The counterweights on the semaphore spring both the home and distant signals to the horizontal position where they remain as long as there is a pair of wheels on the block.

506. It will be seen from the diagram that a **broken rail** or an **open switch** will open the track circuit and cause the signals to return to danger the same as if there were a car in the block.

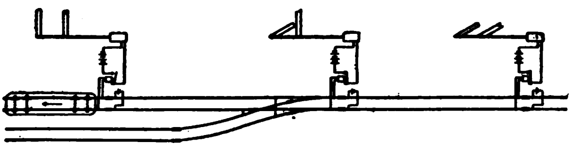


FIG. 121.—D.c. signal circuits (2-track steam roads).

507. The **batteries** employed for the operation of these signals are usually of the gravity cell type located at the side of the track in water-proof man holes below the frost line to prevent freezing in cold weather. On some of the large four track systems storage batteries are used and charged from a main generating plant.

508. In applying this system to electric railroads, the difficulty occasioned by the use of the rails as a return circuit for the trolley current as well as for the signal current prevents its operation on these lines without some modifications.

509. Fig. 122 shows diagrammatically a **two-rail system** employed on electric roads, whereby alternating current at 25-cycles is used for operating the relays which are commonly known as two-phase relays. Each section in addition to being insulated from other sections is provided with inductive bonds connected between the rails at each end. The return current has thus a completé metallic return circuit around insulated joints since the middle points of two adjacent bonds are connected together with a heavy cable capable of carrying the entire return current. One half of this current (if both rails are equally well bonded) will be through the inductive bonds in one direction and half in the opposite direction, and hence will annul the magnetic effect produced by the other half, leaving the iron core practically non-magnetized.

510. In order to insure that the iron core will not become saturated by an unbalanced direct current in case of a poor bond on one rail, an air-gap is made in the core to increase its reluctance, thereby resulting in a considerably reduced cross-section of the iron.

511. The relay in this system has impressed upon it alternating e.m.f. from two sources—the single-phase transmission line and the track circuit. On account of the inductive nature of the rails and the inductive bonds, the current in the track circuit lags considerably behind the e.m.f. and hence the current in one winding of the relay is out of phase with the current in the other, producing a so-called revolving field, causing the relay to operate and closing a second circuit through a battery which operates the signals. Since both rails are normally of the same potential as regards the direct current, there will be no direct current through the coil of the relay which is connected to the track circuit. Hence the relay is independent of the amount of current back through the rail. The first pair of wheels to run into a

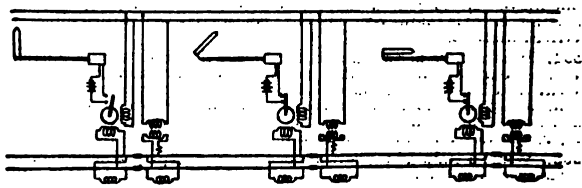


FIG. 122.—A.c. signal circuits (2-track electric roads).

block, short circuits one coil of the relay, causing it to drop out and the signal to turn to danger as in the previous system. When a car is standing at one end of a block and when it approaches the transformers at the other end it has been found necessary to introduce a small iron grid in series with the secondary winding of the transformer in order to limit the current value to a safe amount. In case of a very long block the track resistance becomes so great that it is not feasible to place a transformer at the end of the block but to place it half way as shown in Fig. 123.

512. On **single-phase railroads** where the return current is also alternating this system is operative if alternating current of a different frequency

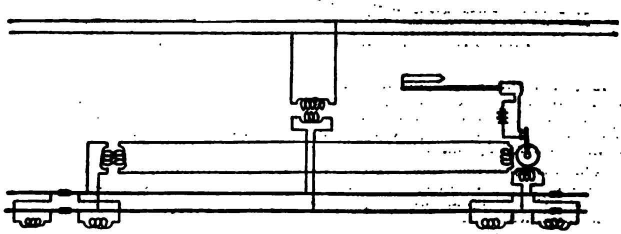


FIG. 123.—A.c. signal circuit, long block (2-track electric roads).

than the trolley is substituted. A 50-cycle signal circuit has been found to give good results when operated on a 25-cycle trolley system.

513. Fig. 124 shows a **single-rail signal system** which requires the insulation of only one rail, the other being bonded for the return trolley current. In this system no inductive bonds are required, but it becomes necessary to protect the relay from stray direct currents by inserting an iron grid in series with the relay coil. The relay is of the split-phase type similar in principle to the single-phase fan motor, whereby the current in one portion of the winding is made to lag behind the current in the other portion, thereby producing a revolving field. This system is particularly well adapted for use in short yard blocks or where use can be made of other conductors in the vicinity to compensate for the loss of one rail in the return

circuit, or where the cost of installing inductive bonds for two-rail system would be prohibitive.

514. The problem of providing a suitable **automatic block signal system for single-track roads** has involved the expenditure of so much capital that few roads have found it in their power or advisable to do so in view of the present state of the art. However, certain pressure has been brought to bear where disastrous wrecks have occurred due to telegraph operators neglecting their duties or engineers attempting to steal a switch, and many railroads are installing a single-track block signal system in preference to laying a double-track where the traffic itself is not sufficient to require one.

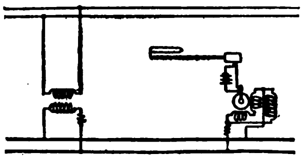


FIG. 124.—1-rail system.

515. A train on a single track road must not only protect itself against following trains but also against opposing trains, and hence must set signals behind and in front of it. Properly speaking, a train on entering a section of single track between two adajcent sidings should set a signal at the next siding, thus preventing another train entering from the other end, but this is impractical in case of a long section of single track and really not essential since certain trains have preference over others and the engineer and conductor are instructed to remain on the siding until such a train has passed. Hence it remains to provide against the possibility of an engineer not being warned when disregarding his orders and running by a passing point.

516. Fig. 125 shows diagrammatically the **principles of a single-track system** for steam roads. The arrangement of track circuits is such that every other insulated section controls signals for trains going in one direction

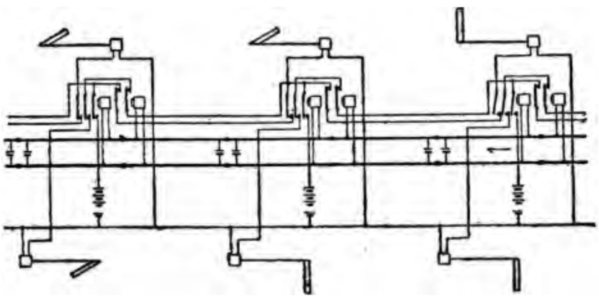


FIG. 125.—D.c. signal circuits (1-track steam road).

and the remaining sections control signals for trains in the opposite direction. These signals are placed on opposite sides of the track so that they will be in view of the engineer when the train is going in either direction. These signals, moreover, are suitably interlocked by means of auxiliary contacts on the track relays so that the train is actually protected for at least three blocks ahead.

517. The operation of the relays and signals is the same as previously described in connection with double track signals, except that the signals are dependent upon three relays instead of one. Assuming a train entering a block in the direction of the arrow and neglecting previous signals, it will be seen that one signal is set behind the train and two in advance. Upon entering the next block an auxiliary contact on the next relay prevents the operating circuit from being closed through the signal protecting its rear, and an-

other auxiliary contact prevents the signal farthest in advance from ret ing to clear. The intermediate signal, however, returns to clear and opera is repeated on entering the succeeding block. Hence it will be seen that nals which are set for the guidance of trains going in the opposite directio turn to clear as soon as they are passed and the other signals turn to da upon passing the signal and remain at danger while the train is run through three blocks.

518. Normal-clear versus normal-danger signals. The signals thu described operate on what is known as the normal clear plan, that is, stand at clear when the block is unoccupied and move to danger aft train has passed. Another plan is known as the normal danger plan, th all signals stand at danger whether the block is occupied or not and n to clear when the train has approached within a certain distance of signal, moving to danger again when the train has passed. The latter sy possesses several advantages if the road is operated by telegraph for pa the distance, but it is doubtful if a majority of these advantages do disappear if the principles of the absolute block system are strictly adh to, inasmuch as the added complication means more weak points in the tem.

519. Trolley operated signals. Thus far only those signal syst have been considered which have been the outgrowth of systems mor less perfected by their use on steam roads. Many trolley roads are only single track lines connecting two large cities twenty or thirty r apart, but in order to compete with existing steam trains it is necessar provide sidings to accommodate a more frequent service and to provi simple signal to give the motorman authority to proceed or stop, and avoid delay and the danger of meeting a belated car between sidings.

520. A very simple device which has been used quite extensively on lines is shown in Fig. 126. Here the motorman throws a switch on ente a block, thereby lighting a light at both ends of the block and throws other switch on leaving, thus putting out both lights. One objectio this system is as follows:

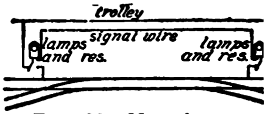


FIG. 126.—Manual system.

521. A motorman at one end of the block seeing a car going in his direction will follow, but being delayed in the block may not be able to keep in sight of the preceding car, hence when the first car leaves the block the car which has been waiting immediately enters and is met between sidings by the second car which has followed. Thus one car will have to return to the siding and in the meantime other may have come up, all of which have been delayed by the time it has ta to change ends, thus bringing about a blocade.

522. Fig. 127 shows an **automatic scheme** for accomplishing the s results: the switch originally thrown by the motorman is here operated by an electromagnet energized by the trolley passing an insulated contact whereby a circuit is closed through the trolley wheel and through an electromagnet to ground. This scheme is open to the same objection as the original method as regards following cars, but by placing lights throughout the block the motorman can tell whether the signal has been disregarded after he has entered. It is doubtful, however, whether this is any real *vantage to him* unless he knows whether there is a car following or op *ing him.*

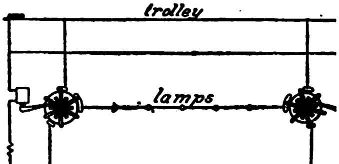


FIG. 127.—Automatic system.

523. *Fig. 128* shows a scheme whereby **three indications** are give *stead of two* as in the previous system. This diagram illustrates a pri *rather than* any particular apparatus manufactured for this purpose, s

the present time a great many signals operating on practically the same principle are being tried by a number of street railroads with more or less success.

524. The idea of this system is to give an indication when the block is clear, and if occupied, to give some indication of the direction of motion of the car in a block; in other words, it allows a car to enter a block into which another car has just preceded it, going in the same direction. This evidently saves considerable time and certain confusion in case the blocks are short, inasmuch as the motorman waiting at one end will see a second car approaching and will wait until it has passed out of the block before proceeding. It is therefore not essential to provide protection for a second car. If a car were held waiting at each end of a block until the signals showed clear, some confusion would arise due to both cars trying for the block at the same time, and one of them being unable to stop promptly on seeing the signal against him would have to back into the siding again. It will be seen, however, that the scheme just illustrated does not provide any protection for the second car, and unless it can keep within sight of the first it is liable to cause more confusion than if it remained behind.

525. The lamps in this system are controlled by a double throw electrically operated switch in each signal. The passage of a trolley wheel over an insulated pendant switch closes a circuit through an electromagnet operating a double throw switch and lights a green lamp at the entering end and a red lamp at the leaving end. In series with the red lamps is a coil of a relay which opens the control circuit which operates the lighting switch in the signal at the other end. Hence there will be no doubt which car has the block if two cars enter almost simultaneously from opposite ends since the second car will fail to light a green lamp; instead, a red light will show.

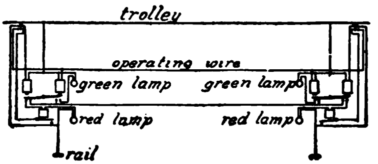


Fig. 128.—Automatic system.

526. To avoid the necessity of the conductor getting off and turning the switch to allow a car which has passed the trolley switch in this manner to back into the siding again, the **trolley switch** is **placed** some distance from the end of the siding, thus allowing the motorman opportunity to back his car over the trolley switch so as to be able to set the signal when he enters. Two trolley switches are therefore required at each end since the car leaving the block passes on a different track. Care should also be taken in placing the trolley switch for clearing the signal in so far as to insure that a car entering the siding will pass the switch before the waiting car can start, leaving fewer chances for a car to enter without setting the signals.

527. In some instances where **both local and interurban cars** run over a **short** section of **single track** with many curves, or during a heavy excursion when the bulk of the traffic is in one direction, it is advantageous to permit several cars to enter a block and protect each one by leaving the signals set until the last car has passed out. Such a signal can be arranged to accommodate any number of cars, counting them in and out, but when arranged to accommodate very many it is manifestly unjust since a number of cars may have passed in one direction before a single car is allowed to proceed in the other. In addition to this, many of the cars which have passed through one block may be held up at the next siding by cars coming through the next block, and unless the sidings are sufficient to accommodate all, confusion will arise in switching them by each other, whereas if some were made to wait at the preceding siding no such delay would be occasioned. When limited to a few cars this system possesses several advantages under certain operating conditions which are not possessed by the previous system, especially if the track is crooked, or the vision limited otherwise.

528. Fig. 129 shows diagrammatically a **car-counting system.** A double throw switch pivoted at its center is notched around by two pawls which are operated by two electromagnets energized from the trolley wire through a trolley operated switch. A car on entering closes the circuit for an instant through one electromagnet, notching up the signal switch one notch, and

closes a circuit through a series of green lamps spaced through the block and a red lamp at the other end. Every additional car notches the switch further around and in leaving, notches it back so that the last car out leaves the switch in its original position.

529. The **trolley switches** in this system are usually placed in the single track portion of the trolley, so that one switch at each end serves for cars running in both directions. When a motorman finds a signal against him after it is too late to stop before passing the trolley switch, he should back out with his trolley off when passing under the trolley switch since his entrance failed to register on the proper signal and consequently should avoid registering out in order to leave the signal set properly for the first car to register going in. Introducing a relay in much the same way as is done in the previous system prevents the opposing signal registering when a car enters in this manner. It can then back out with the trolley on without distributing the adjustment, since the absence of a tooth in the ratchet wheel will prevent the switch moving beyond normal when counting out.

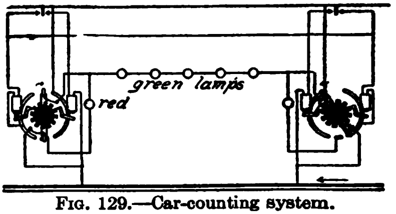


FIG. 129.—Car-counting system.

AUTOMATICALLY OPERATED TRACK SWITCHES.

530. The practice of turning switches with switch bars from the front platform of cars has been made practically impossible by the addition of the vestibule and fender, and many roads have undertaken to install electrically operated switches and thus avoid the inconvenience and waste of time oc-

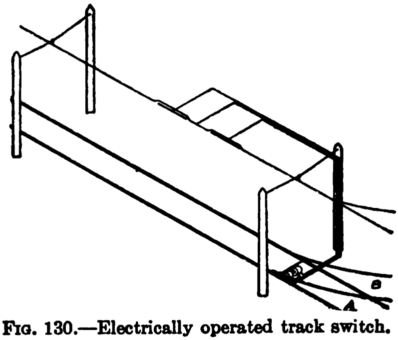


FIG. 130.—Electrically operated track switch.

casioned by requring a motorman or conductor to get off the car and turn them, or employing a switch tender. Usually the **hand-operated switches** are held in place by a block of rubber or piece of steel to prevent splitting the switch as often happens in case of double track cars, and these small blocks frequently require considerable manipulation before they are taken out and the switch turned. An **electrically operated switch** is turned at will by the motorman running over an insulated section of the trolley with power on, or left in its original position by coasting over this section. Perhaps the simplest manner by which a switch may be turned is by placing two solenoids between the tracks at the switch and connecting their cores to the switchpoints. By energizing either of these solenoids the switch will be turned in one way or the other, and it remains to place two insulated sections in the trolley wire whereby a car can cause current through one or the other, or neither.

531. The following are the **ways in which the switch may be operated**:

(1) A motorman wanting to go in the direction, "A," may find the switch set for track, "A," in which case he may either coast over both insulated sections or run over that section which will not disturb the switch with power on and coast over the other, or if the sections are in proper sequence he can run over both with power on.

(2) If the switch is set against him, the motorman must select the insulated section which will turn the switch and run it with power on. If it is the last section he can run over both sections with power on.

(3) Likewise, if the car intends to run in the direction, "B," but if the sections are arranged for all the combinations mentioned above for the direction "A," there will be one less combination by which the switch can be operated by the cars going in the direction, "B."

532. If the **switch** is **on a down grade** for approaching cars the arrangement of sections before the switch points proves satisfactory since the car can coast over both sections if necessary, whereas if the approach to the switch is on a considerable up grade it would be difficult to coast very far at the speed permissible on the grade. Hence one insulated section is sometimes placed in the trolley beyond the switch, in which case a car will run over the first section with power on, setting the switch for track, "A," and then reset it for track, "B," by running over the second section with power on. Cars for track, "B," will coast over the first section.

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Numbers refer to sections, not pages.

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